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The Relative Efficiency of Some Copper Dusts and Sprays in the Control of Potato Diseases and Insect Pests

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CONTENTS

PAGE

Nature of copper-lime dust 3
Precipitation membranes 4
Adhesion of dust and spray mixtures 8
The copper test 9
Dust on wet foliage compared with spray on dry foliage 10
Greenhouse experiments 10
Field experiments 11
Dust on wet and on dry foliage 14
Greenhouse experiments 14
Field experiment 16
Comparison of various copper dusts on wet foliage 18
Greenhouse experiments 18
Field experiment 19
Relative toxicity of bordeaux mixture and copper-lime dust to *Phytophthora infestans* 21
Spore-germination tests 24
Infection experiments 26
Experiments with dusts and sprays 27
Copper-lime dust compared with bordeaux mixture 28
Experiments of 1920 28
Experiments of 1921 31
Experiments of 1922 41
Summary of results for 1920, 1921, and 1922 45
Comparison of effectiveness of copper-lime dust applied to wet and to dry foliage 48
Efficiency of copper-lime dusts containing different percentages of copper 50
Comparison of copper-lime dust with sulfur dust 51
Copper-lime dust compared with nicotine dusts for aphis control 53
Injury to potato plants from fungicides containing copper 55
Change in soil reaction resulting from application of fungicides 60
Relative costs of dusting and spraying 61
Summary 62
Bibliography 65

THE RELATIVE EFFICIENCY OF SOME COPPER DUSTS AND SPRAYS IN THE CONTROL OF POTATO DISEASES AND INSECT PESTS[1]

ORAN CECIL BOYD

Dusting for the control of plant diseases has received almost constant consideration by the Department of Plant Pathology at Cornell University since the revival of the practice of sulfur dusting in 1910 (Blodgett, 1913, 1914).[2] Since 1912, orchard dusting with sulfur-arsenate mixtures in several sections of the country, including New York, has in part replaced the sulfur sprays. As a result of the work of Sanders and Kelsall (1918), a new interest was created in the use of a copper dust which differed from the various brands of bordeaux powders by containing its copper in the form of dehydrated copper sulfate.

In 1919 and particularly in 1920, the Department, through its fellowships, extended the dusting investigations to include vegetables and truck crops, employing the dry copper preparations mentioned above in comparison with standard bordeaux mixture. During these years promising results were obtained, especially on potatoes and celery. In 1921, on the strength of these preliminary trials, a special investigation[3] in the dusting and spraying of potatoes was begun, the results of which are recorded herein.

The purpose of the investigation was to compare certain dusts and spray mixtures, particularly copper-lime dust with bordeaux mixture, in the control of potato diseases and insect pests. Emphasis was placed upon late-blight and flea-beetle control. Regarding the problems for consideration, special weight was given to such phases as the relative adhesiveness of the fungicides and their effectiveness in control, the cost of application, and the types of dusting and spraying machinery. Attention was given also to other factors which appeared to influence the effectiveness of the fungicides under trial. The character of the experiments was adjusted to the particular problems in the sections concerned. The greater part of the experimental work was conducted in Suffolk County, Long Island. In 1921, additional experiments were performed in Washington County.

NATURE OF COPPER-LIME DUST

The material known as " Sanders' dust," or copper-lime dust, consists of a mixture of partly dehydrated copper sulfate, and hydrated lime. Mixtures that contain no arsenates are generally referred to as 15–85 dust, 20–80 dust, and so on, depending on the ratio of monohydrated copper sulfate to hydrated lime. If the dust includes a poison, the poison is usually supplied in the form of calcium arsenate. Such a mixture, for

[1] Also presented to the Faculty of the Graduate School of Cornell University, July, 1923, as a major thesis in partial fulfillment of the requirements for the degree of doctor of philosophy.

AUTHOR'S ACKNOWLEDGMENT. The writer extends his thanks to Dr. F. M. Blodgett, under whose direction the work was conducted, for many helpful suggestions and criticisms.

[2] Dates in parenthesis refer to *Bibliography*, page 65.

[3] The investigation was conducted under the provisions of the Herman Frasch Fellowships.

example, is the 15–8–73 dust, in which eight pounds of lime of the 15–85 formula has been replaced by an equal weight of calcium arsenate. On the other hand, similar dusts have been referred to by Sanders and Kelsall (1918, 1920) as 5–2 and 9–5 dusts, the numbers representing the percentages of metallic copper and arsenic, respectively.

The precipitate that is formed when copper-lime dust is applied to damp foliage resembles, to a marked extent, the covering produced by a bordeaux mixture rich in lime. If the dust is applied to a wet surface, or to a dry surface to which water is added subsequently, the copper salt undergoes hydration, passes into solution, and combines with the lime to form a blue bordeaux mixture. Such a dust may be said to represent an "incomplete" bordeaux mixture, requiring only the contact with water to complete the preparation.

PRECIPITATION MEMBRANES

The physical nature of the precipitate in bordeaux mixture, as indicated by the investigations of Lutman (1916), Butler (1914), Butler and Smith (1919), Cook (1920), Gastine (1906), and others, determines, to a large extent, the efficiency of the preparation as a fungicide. The important property, adhesiveness, depends primarily upon the physical nature of the precipitation membranes. When bordeaux mixture is sprayed on foliage, the colloidal membranes in suspension slowly settle, partially coalesce as water evaporates from the wash, and finally form a thin gelatinous layer, which, on completely drying, becomes firmly attached to the surface of the leaf.

No references in literature were found pertaining to the physical properties of the precipitate formed by the copper-lime dust. It was considered worth while, therefore, to make microscopical examinations of the dust layer, noting the size, the shape, and the surface-covering power of the precipitated copper-containing particles as compared with the membranes in bordeaux mixtures. It might thus be possible to explain differences in the degree of adhesiveness of the two fungicides.

In studying the dust coating, the following procedure was observed. A series of glass plates of uniform size were dusted with a hand machine applying equal amounts, with uniform distribution, of the dust to be examined. No differences were noted in the character of the precipitates when slides sprayed with water previous to being dusted were compared with slides dusted while dry and given moisture later. After the slides were exposed in the open for two days or longer, they were divided into two series. One series was tested for the amount of copper per unit area, the other was reserved for an examination of the precipitate.

In the study of the precipitation membranes of bordeaux mixtures, the procedure was essentially the same as the method employed by Lutman (1912 b). A standard bordeaux mixture was prepared from copper sulfate and freshly prepared hydrated lime.[4] From this stock solution, dilutions of varying degrees were made. The mixture obtained from a 4–4–50 bordeaux preparation by making three successive dilutions is represented by the formula $\frac{1}{2}$–$\frac{1}{2}$–50, and contains one-eighth as much copper per unit

[4] In all of the formulae given in this paper which refer to bordeaux mixtures, the number representing the proportion of lime, unless otherwise designated, refers to calcium hydroxide.

volume as does the original stock solution. Before known amounts of the dilutions were removed for membrane study, the mixtures were sprayed from a hand sprayer into flasks, for the purpose of converting the suspension into a fine mist. The colloidal membranes were thus broken, and, when studied microscopically, might be said to represent the form and distribution that would be obtained when the mixture is sprayed on plants. Two-tenths of a cubic centimeter of the sprayed dilution was then pipetted upon a clean glass plate, the surface of which had been moistened with an extremely thin film of a dilute aqueous solution of gum arabic. This film permitted the bordeaux solution to spread out rapidly into a large, thin, circular drop. After the mixture had dried and the slide had been exposed to the air for forty-eight hours, the precipitate was stained with a dilute solution of potassium ferrocyanide in acetic acid. The same stain was employed for the dust precipitate.

The relative size, shape, and distribution of the dust and spray membranes were determined by tracing the outlines with the aid of a camera lucida. To estimate the percentage of surface covered by the copper membranes, the outlines were cut out, the paper was weighed, and its weight was compared with the weight of the original sheet representing the field. When mixtures more concentrated than a $\frac{1}{2}$–$\frac{1}{2}$–50 bordeaux were spread on the slide, the precipitate that remained after drying was in the form of a more or less continuous layer. Or, if a reasonably heavy application of dust was made, no well-defined individuality of membranes could be detected. For this reason, sufficiently high dilutions of sprays and light applications of dusts were made to permit a comparison of the two kinds of membranes.

The dust membranes (figure 1) stain red with the acid-potassium-ferrocyanide stain, are colloidal in nature, and, before drying to the surface, are more or less entire and usually spherical. They possess a rather thick wall and a relatively high specific gravity. The spray membranes, on the other hand, in a dilution as high as $\frac{1}{4}$–$\frac{1}{4}$–50, are small, exceedingly irregular in outline, and very thin as compared with the dust membranes (figure 2). They represent minute, ruptured fragments of larger, smoother membranes characteristic of the lower dilutions (figure 3). The dust membranes, after they have dried to the sur-

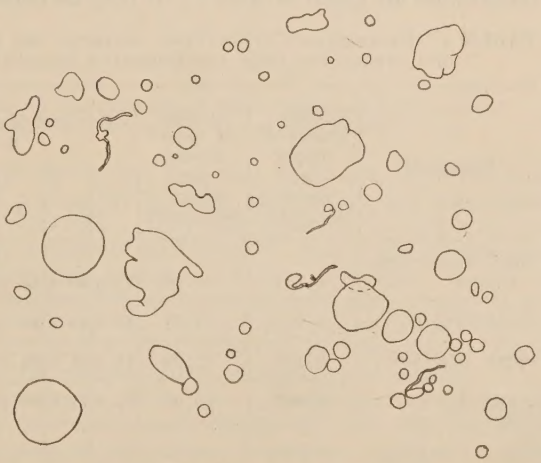

FIGURE 1. MEMBRANES OF A COPPER-LIME DUST APPLIED TO A WET SLIDE AND ALLOWED TO DRY; REPRESENTING 0.323 MILLIGRAM OF COPPER PER SQUARE DECIMETER. × 30

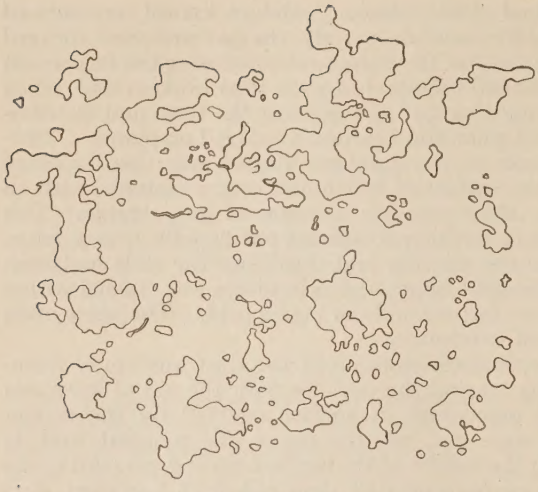

FIGURE 2. BORDEAUX MEMBRANES OF A 4–4–50 CONCENTRATION DILUTED TO $\frac{1}{4}$–$\frac{1}{4}$–50, PIPETTED ON A GLASS SLIDE, AND ALLOWED TO DRY; REPRESENTING 0.34 MILLIGRAM OF COPPER PER SQUARE DECIMETER. × 30

face, resemble closely in texture, thickness, and other characteristics, the membranes in bordeaux mixtures varying in strength from $\frac{1}{2}$–$\frac{1}{2}$–50 to 1–1–50, but usually remain circular in outline, flattened, and entire (figure 1).

The stained membranes of a $\frac{1}{8}$–$\frac{1}{8}$–50 bordeaux mixture (figure 4) were so thin that the outlines could be followed only with difficulty in making the camera-lucida drawings. The membranes of the 1/16–1/16–50 mixture were too small to follow, in tracing outlines on paper with the use of a 16-millimeter objective and a 15-× ocular, and they were entirely too thin and hyaline to be observed with any degree of definition with the use of an 8-millimeter objective and an 8-× ocular.

The results of the study of the size and distribution of the spray and dust membranes are given in table 1. It may be noted, by comparing the first

TABLE 1. RESULTS OF COPPER TESTS SHOWING THE RELATIVE COVERING POWER OF COPPER-LIME DUST AND BORDEAUX MIXTURE ON GLASS PLATES

Fungicide	Milligrams of copper per square decimeter	Number of membranes per square millimeter	Per cent of surface covered in trial						Relative covering value per milligram of copper
			1	2	3	4	5	Average	
Dust (10-per-cent copper).....	0.323	11.20	23.3	20.4	24.3	25.4	....	23.35	72.30
Spray ($\frac{1}{2}$–$\frac{1}{2}$–50)...	1.000	5.33	42.1	44.2	44.0	....	....	43.43	43.43
Spray ($\frac{1}{4}$–$\frac{1}{4}$–50)...	0.340	27.20	33.5	31.6	29.0	31.2	32.8	31.62	93.00
Spray ($\frac{1}{8}$–$\frac{1}{8}$–50)...	0.098	66.00	19.0	17.6	18.7	....	....	18.43	188.00

two columns of figures, that as the bordeaux mixture was diluted by adding, each time, a volume of water equal to that of the original volume, the number of milligrams of copper per square decimeter was reduced by more

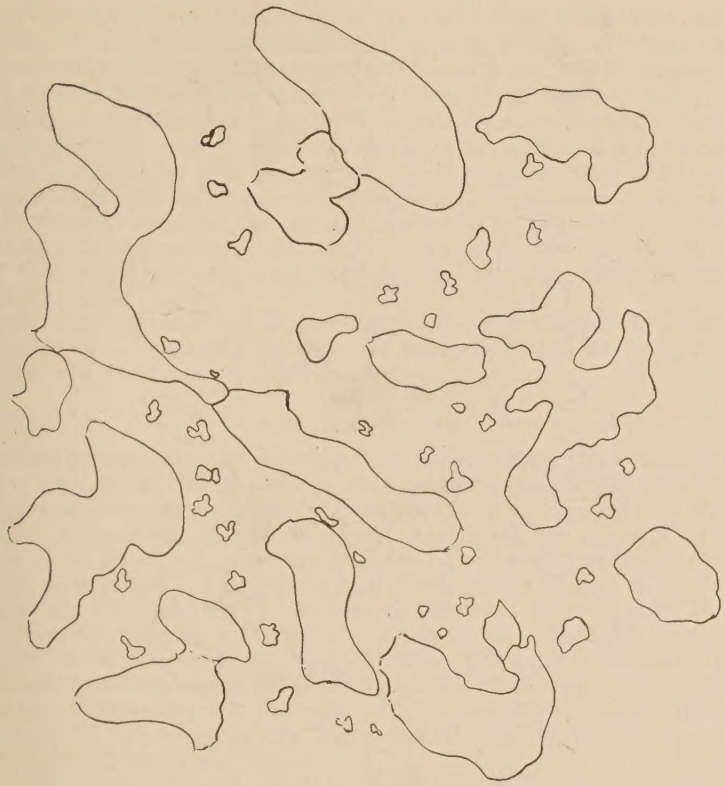

FIGURE 3. SAME AS FIGURE 2 EXCEPT FOR DILUTION, WHICH IS $\frac{1}{2}$–$\frac{1}{2}$–50, REPRESENTING 1 MILLIGRAM OF COPPER PER SQUARE DECIMETER. × 30

than one-half. This was due to the fact that the more dilute solutions tended to spread more and cover a larger area before the membranes settled to the surface of the slide. It is also apparent, in comparing the figures representing the number of milligrams of copper per square decimeter with the corresponding averages for the percentage of surface covered, that more surface per unit of copper present was covered at the lower concentrations. This increase in covering power is undoubtedly due to the fact that in the lower concentrations the membranes are broken into smaller and thinner membranes with less tendency to overlap.

The $\frac{1}{4}$–$\frac{1}{4}$–50 bordeaux mixture, which gave 0.34 milligram of copper per square decimeter, seems to be most nearly comparable with the dust, which gave 0.323 milligram of copper per square decimeter. Comparing these (figures 1 and 2), it is seen that there were more than twice as many membranes per unit area on the sprayed surface and that they covered a larger percentage of the area. This condition seems to result from the fact that the globular membranes which are formed in dusting a wet surface dry down entire, with double thickness, and are not broken up afterward

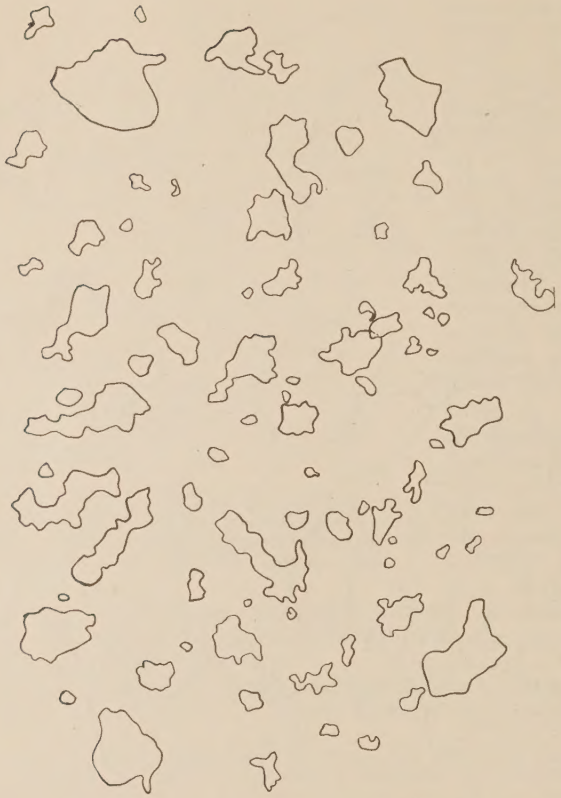

FIGURE 4. SAME AS FIGURE 2 EXCEPT FOR DILUTION, WHICH IS $\frac{1}{5}$–$\frac{1}{6}$–50, REPRESENTING 0.098 MILLIGRAM OF COPPER PER SQUARE DECIMETER. × 60

and scattered, as are the spray membranes. It therefore seems reasonable to suppose that a more even distribution of the copper precipitate is possible with the spray than with the dust.

ADHESION OF DUST AND SPRAY MIXTURES

In referring to the relative adhesiveness of dust and spray mixtures, Sanders and Kelsall (1920), in reporting the results of their potato dusting and spraying experiments in 1919, state that although approximately equal amounts of copper adhered to the leaves from the copper-lime dust and from the bordeaux mixture during the applications, subsequent copper tests showed that the spray possessed a higher degree of adhesiveness than did the dust. The authors recommended that, in order to obtain the maximum adhesiveness with the dust, one should dust when the foliage is thoroughly moist and the wind is low.

In the preliminary field experiments conducted by the writer in 1920, in which two copper dusts were used in comparison with spray mixtures,

foliage dusted in the early morning, when a heavy dew covered all parts of the tops, always showed a more prominent blue coating, after the fungicide had dried, than did plants that were dusted when little or no moisture was present. Such was the observation when either Sanders' dust or the dry bordeaux preparation known as " bordeaux-lead "[5] was used. Furthermore, the copper coating on the foliage sprayed with the lime-bordeaux mixture appeared to undergo less washing from rains than did that on dusted foliage, and the copper-lime dust seemed to possess a higher degree of adhesiveness than did the dry bordeaux preparation and to be about equal to soda-bordeaux in that respect. As no field tests for copper were made that year, no definite data were obtained regarding the adhesiveness of the fungicides in use.

Since adhesiveness is one of the important properties which determine the value of a fungicide, experiments were conducted to compare the adhesiveness of several fungicides.

THE COPPER TEST

For the determination of the amount of copper on foliage, a method was sought that would be adapted to both laboratory and field conditions. The general procedure followed was that outlined by Winston and Fulton (1919). The method, in brief, consists in immersing 200 grams of sprayed leaves in 1 liter of a 0.2-per-cent solution of nitric acid until the copper coating is dissolved. A few drops of a dilute solution of potassium ferrocyanide are then added to a portion of the wash and the color of the suspension is compared with that of a series of color standards previously prepared to represent varying concentrations of copper in terms of milligrams per 100 centimeters of solution. A few alterations in the method were found necessary for the sake of obtaining more nearly accurate results. The following include the principal changes in the procedure outlined by Winston and Fulton:

(1) The amount of acid wash for dissolving the copper was increased two- or three-fold.

(2) After washing the leaves, the solution was rendered alkaline with concentrated ammonium hydroxide, and reacidified to a point slightly acid to litmus. Unless this precaution is observed, the maximum copper reaction cannot be depended upon when potassium ferrocyanide is added. By observing it, extremely delicate tests can be made.

(3) Instead of using copper-sulfate crystals alone in making up the standard solutions for color comparisons, a bordeaux mixture was prepared from freshly slaked lime and a solution of copper sulfate which had previously been standardized for copper content. A certain volume of this mixture was poured into a wide-bottom glass vessel and allowed to dry and to undergo ordinary weathering in the open for two or three days. The precipitate was then treated exactly as the coating on the dusted or the sprayed leaves, that is, it was dissolved in the acid wash and the latter was brought to the proper degree of acidity. When dilutions for color standards are made from such a stock, the suspension which is formed when potassium ferrocyanide is added is more nearly comparable to that

[5] This proprietary mixture, furnished by Riches, Piver & Co., of New York City, represents an evaporated bordeaux mixture containing arsenate of lead. The powder contains 11½ per cent of metallic copper and 15 per cent of arsenate of lead. The directions provide for its use as either a dust or a spray.

obtained in the wash from the foliage than to the more or less permanent suspension that results from the addition of the same indicator to dilute solutions of pure copper sulfate. For the most accurate determinations, the indicator should not be added to the dilutions of the dissolved bordeaux stock solution, in preparing the color standards, until the day on which the comparisons are to be made.

(4) Instead of preparing a series of tubes or vials of known dilutions from the stock, and comparing the color of the unknown with those of the standards, only two or three dilutions were made, which represented relatively low copper contents, such as 2, 4, and 6 milligrams per 100 cubic centimeters, respectively.

The indicator was then added to all of the tubes, including a tube containing a definite volume of the foliage wash, and the wash was diluted gradually until the color matched that of one of the standards. The copper content of the original wash was determined by a simple calculation. The most accurate comparisons can be made only with rather dilute solutions, that is, solutions containing from 2 to 5 milligrams of copper per 100 cubic centimeters. It is highly important that test tubes with uniform thickness and color of walls, and uniform diameter, be used.

In comparing the relative adhesiveness of dusts and bordeaux mixtures, both greenhouse and field experiments were conducted. The field determinations were made by comparing the results of copper tests from the foliage of plots under different treatments. The greenhouse experiments were conducted under more accurately controlled conditions with reference to the uniformity in amount and distribution of the fungicides upon the plants. In the greenhouse investigations, potato plants uniform in size were dusted or sprayed, on both the upper and the lower surfaces of the leaves, with equal amounts of the material for each plant. After the fungicide had dried on the foliage, the foliage was tested for copper before and after washings. Half of the leaves of each plant were removed before the washing. In all cases the washing consisted of a slow shower of 3 or 4 liters of water for each plant. The dusting and the spraying of glass plates were also included in the investigations conducted in the greenhouse.

DUST ON WET FOLIAGE COMPARED WITH SPRAY ON DRY FOLIAGE

Greenhouse experiments

Experiments conducted in the greenhouse, on both potato foliage and glass plates, indicate that the coating from bordeaux mixture 4–4–50 sprayed on dry surfaces is more resistant to the washing action of artificial rains, than the covering formed by dusting wet surfaces with a copper-lime dust containing 10 per cent of copper. In the experiment in which glass slides were dusted and sprayed (table 2), there seems to be a significant difference,[6] a little more than 15 per cent, in the percentage of copper that

[6] The probable error given in the tables throughout this paper was computed with Bessel's formula,

$$P.E._{M} = \pm 0.6745\sqrt{\frac{\Sigma d^2}{n(n-1)}}$$

Where the results of two treatments were to be compared, the treatments were usually made so that they could be compared in pairs. The difference was taken between the two treatments of a pair. These differences were then averaged and the probable error of the mean was computed from the individual differences. It is believed that in this way, especially when the method is applied to field experiments, the effects on the results of the variations due to soil and climatic conditions from one part of a field to another, and from one field to another, as well as from one year to another, can be minimized.

TABLE 2. RESULTS OF EXPERIMENTS TO COMPARE THE ADHESION OF COPPER-LIME DUST AND BORDEAUX SPRAY TO GLASS PLATES

Experiment no.	Milligrams of copper per square meter of plate				Per cent of copper adhering after washing	
	Dusted		Sprayed			
	Before washing	After washing	Before washing	After washing	Dusted	Sprayed
1	2.94	2.20	2.64	2.33	74.83	88.26
2	4.50	4.10	3.35	3.35	91.11	100.00
3	3.00	2.15	1.83	1.61	71.67	87.98
4	1.95	1.40	2.25	2.14	71.79	95.11

Average difference in percentage of copper remaining on the glass plates = 15.48 ± 1.923, in favor of the spray

remained after the washing, in favor of the spray. In the experiment in which the comparison was made on potato leaves (table 3), the difference, while not so great, appears to be regular and significant throughout the five tests. In this case the average difference in the percentage of total copper

TABLE 3. RESULTS OF EXPERIMENTS TO COMPARE THE ADHESION OF COPPER-LIME DUST AND BORDEAUX SPRAY TO POTATO FOLIAGE IN THE GREENHOUSE*

Experiment no.	Milligrams of copper per 100 grams of green leaves				Per cent of copper remaining on leaves	
	Dusted		Sprayed			
	Before washing	After washing	Before washing	After washing	Dusted	Sprayed
1	120	85	138	115	70.83	83.33
2	140	100	100	85	71 43	85.00
3	160	125	88	80	78.13	90.91
4	180	140	144	117	77.78	81.25
5	105	83	90	80	79.05	88.91

Average difference in percentage of copper remaining on the foliage = 10.44 ± 1.25, in favor of the spray

*Irish Cobbler potato plants were used in the first two experiments, and Bliss Triumph in the others.

adhering was slightly above 10 per cent in favor of the spray. In comparing the data in tables 2 and 3, it is seen that the degree of adhesiveness in the case of the dust is about the same on the glass slides and on the leaves, while the spray seems slightly more adhesive to the glass plates than to the foliage.

Field experiments

During the season of 1922, field tests with copper were made from two experiments which involved the dusting of wet foliage and the spraying

of dry foliage. The experiments were conducted at Bridgehampton and Southampton, Long Island. Each experiment included six dusted, six sprayed, and three check plots. At each farm an engine-driven potato duster and a traction sprayer, each with two nozzles per row, were employed. Copper determinations were made from representative samples of leaves taken from the dusted and the sprayed plots before and after successive applications, beginning with the third application.

Results of individual copper tests, together with the dates of the applications of the fungicides, are given in tables 4 and 5 and in figure 5.

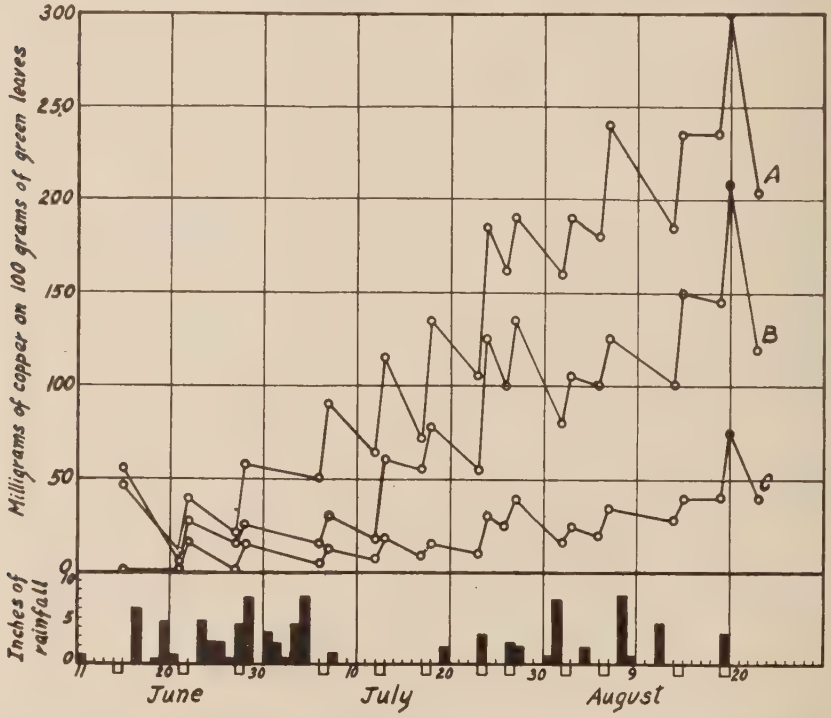

FIGURE 5. RESULTS OF INDIVIDUAL COPPER TESTS MADE ON FOLIAGE (A) SPRAYED WITH BORDEAUX MIXTURE, (B) DUSTED WITH A COPPER-LIME DUST WHEN THE FOLIAGE WAS DAMP, AND (C) DUSTED WITH A COPPER-LIME DUST WHEN THE FOLIAGE WAS DRY, WHEN APPROXIMATELY EQUAL AMOUNTS OF COPPER WERE APPLIED PER ACRE IN EACH TEST

RAINFALL DATA

Date	Inches	Date	Inches	Date	Inches	Date	Inches
June 11	0.1	June 26	0.23	July 4	0.42	July 31	0.1
17	0.6	27	0.07	5	0.71	August 1	0.7
19	0.05	28	0.42	8	0.12	4	0.2
20	0.45	29	0.71	20	0.2	8	0.75
21	0.1	July 1	0.35	24	0.32	9	0.1
24	0.48	2	0.23	27	0.25	12	0.45
25	0.25	3	0.07	28	0.2	19	0.35

TABLE 4. RESULTS OF COPPER TESTS IN FIELD EXPERIMENT 1, ON LEAVES SPRAYED WHEN DRY WITH BORDEAUX 6-4-50, AND ON LEAVES DUSTED WHEN DAMP WITH COPPER-LIME DUSTS CONTAINING 8½ AND 10 PER CENT OF COPPER, 1922

Applications		Pounds of copper applied per acre		Milligrams of copper on 100 grams of green leaves					
				Foliage sprayed			Foliage dusted		
Date	No.	In spray	In dust	Before application	After application	Amount retained	Before application	After application	Amount retained
June 10	1	4.90	3.33	.....	.....	.....	.....	.....	.....
15	2	3.00	3.17	.....	47	.....	.....	56.2	.....
22	3	2.55	3.70	11.7	42	30.3	6.2	26.5	20.3
28	4	3.80	4.00	21.5	59	37.5	15.0	26.6	11.6
July 7	5	3.70	3.00	50.0	90	40.0	16.0	31.0	15.0
13	6	3.90	4.10	63.0	115	52.0	17.0	60.0	43.0
18	7	3.70	3.20	72.0	137	65.0	55.0	78.0	23.0
24	8	4.85	4.85	106.0	187	81.0	56.0	125.0	69.0
27	9	3.50	3.50	162.0	190	28.0	100.0	137.0	37.0
August 2	10	4.75	3.50	160.0	190	30.0	81.0	105.0	24.0
7	11	2.80	2.10	180.0	240	60.0	100.0	125.0	25.0
14	12	5.40	6.00	185.0	235	50.0	100.0	150.0	50.0
19	13	3.80	4.10	235.0	300	65.0	145.0	210.0	65.0
22*	....	.....	.....	205.0	.....	.....	120.0	.....	.....

* On August 22 the final test for copper was made. No application was made on this date.

TABLE 5. RESULTS OF COPPER TESTS IN FIELD EXPERIMENT 2, ON LEAVES SPRAYED WHEN DRY WITH BORDEAUX 6-4-50, AND ON LEAVES DUSTED WHEN DAMP WITH COPPER-LIME DUSTS CONTAINING 8½ AND 10 PER CENT OF COPPER, 1922

Applications		Pounds of copper applied per acre		Milligrams of copper on 100 grams of green leaves					
				Foliage sprayed			Foliage dusted		
Date	No.	In spray	In dust	Before application	After application	Amount retained	Before application	After application	Amount retained
June 12	1	2.75	3.0	.....	.....	.....	.....	.....	.....
17	2	2.90	6.0	.....	56	.....	.....	90.0	.....
21	3	3.00	5.0	18	42	24	15	39.0	24.0
27	4	3.00	4.4	20	62	42	16	62.0	46.0
July 3	5	3.45	3.6	25	45	20	25	37.5	12.5
8	6	3.00	5.0	35	70	35	26	62.0	36.0
14	7	3.00	4.6	44	72	28	31	67.0	36.0
19	8	3.80	4.4	71	115	44	65	100.0	35.0
25	9	4.40	5.2	106	144	38	90	130.0	40.0
28	10	3.00	3.0	130	190	60	100	137.0	37.0
August 4	11	4.00	4.7	106	200	94	78	120.0	42.0
8	12	4.25	3.6	190	230	40	105	140.0	35.0
11	13	4.00	5.0	200	265	65	110	170.0	60.0
16	14	3.00	3.0	240	275	35	150	180.0	30.0

A summary of the data for the copper tests is given in table 6, showing averages based on the determinations for each application. The difference in the amount of copper retained by the dusted and the sprayed foliage was determined by comparing the number of milligrams of copper retained by 100 grams of leaves for each pound of copper applied per acre in each application. Likewise, the difference in the adhesiveness of the dust and the spray was determined by comparing the relative losses of copper which occurred after each application and before the following one, and then averaging the differences. Due to the fact that equivalent amounts of copper in the dusts and the sprays were not always applied in corresponding applications, the values obtained from the copper tests were reduced to milligrams of copper for each unit pound of copper applied per acre.

TABLE 6. SUMMARY OF DATA SHOWING THE RELATIVE ADHESIVENESS OF BORDEAUX MIXTURE TO DRY FOLIAGE AND OF COPPER-LIME DUST TO DAMP FOLIAGE

Experiment no.	Average number of pounds of copper applied per acre at each application		Average number of milligrams of copper on 100 grams of green leaves for each pound of copper applied per acre					
			Retained during the application			Washed off before the following application		
	In spray	In dust	Spray	Dust	Difference	Spray	Dust	Difference
1	3.88	3.82	12.93	8.98	3.95 ±1.25	8.87	6.89	1.98 ±0.91
2	3.53	4.40	12.56	8.40	4.16 ±0.81	7.35	6.00	1.35 ±0.61

It will be observed, from the data in table 6, that in both experiments considerably more copper was retained by the foliage from the spray than from the dust, the difference in each experiment being more than three times its probable error. The amount of copper that was lost between applications was also larger with the sprayed foliage, due presumably to the proportionately greater quantity that was retained by the leaves. These differences, however, which indicate a greater loss of copper in the sprays than in the dusts, are considerably less than three times their probable errors, and their significance is therefore questionable. The percentage of copper that remained on the foliage after washings between applications was greater on the sprayed plants in both experiments, but it was significantly larger only in experiment 2, in which the difference was more than three times its probable error. It will be seen from the data in table 5 that, although there was more copper applied in the dust than in the spray throughout the season, the last copper test for experiment 2 showed about 52.8 per cent more copper on the leaves sprayed with bordeaux mixture than on the dusted leaves. Likewise, in the case of experiment 1, as shown in table 4, the copper test that was made immediately after the last application showed about 43 per cent more copper on the sprayed leaves, and the last test showed about 71 per cent more.

DUST ON WET AND ON DRY FOLIAGE

Greenhouse experiments

In order to determine the relative amounts of dust that would be retained by dry foliage and by wet foliage, twelve Bliss Triumph plants were dusted with an equal amount of a copper-lime dust containing 9 per cent of copper. Six of these plants were previously sprayed uniformly with water, and the remainder were left dry. The results of four experiments, expressed in milligrams of copper retained on 100 grams of green leaves, were as follows:

Experiment	On wet foliage	On dry foliage
1	40	20
2	180	80
3	190	95
4	92	45

These data indicate that, under such conditions, moistened leaves will retain about twice as much dust as will dry leaves, when equal amounts of

the dust are applied. Therefore, in order to get a certain amount of dust on the leaves, it is necessary to use twice as much material when the vines are dry.

In the experiments discussed above, it was observed that when leaves which were dusted when dry were moistened subsequently with a fine spray of water, in an amount just sufficient to allow the fungicide to "set" but not enough to permit an accumulation of large drops or any dripping, the dust coating that resulted after the foliage had dried was more evenly distributed over the surface of the leaflets than the covering on foliage that was dusted when moist. With this in mind, experiments were next conducted to determine whether there was any difference in the adhesiveness of a copper-lime dust when applied to wet foliage and when applied to dry leaves that were moistened subsequently. The plants that were dusted dry were divided into two series, one of which was moistened immediately and the other on the following day. There were six plants in each series, in each experiment. Before the plants were subjected to an artificial rain, half of the leaves were removed for controls. Green Mountain plants were used in the first experiment, and Bliss Triumph plants in the others.

The results of the copper tests for the plants dusted when dry are given in table 7, and those for the plants dusted when wet are given in table 3 (page 11). Only in the third trial was there any indication that a delay

TABLE 7. RESULTS OF COPPER TESTS TO DETERMINE THE EFFECT OF SUBSEQUENT WETTING OF FOLIAGE ON THE ADHESIVENESS OF A COPPER-LIME DUST, CONTAINING 10 PER CENT OF COPPER, APPLIED TO DRY FOLIAGE

Experiment no.	Milligrams of copper on 100 grams of green leaves				Per cent of copper remaining after washing	
	On plants moistened immediately after the dusting		On plants moistened one day after the dusting		Immediate wetting	Delayed wetting
	Before washing	After washing	Before washing	After washing		
1.....	110	95	110	90	86.36	81.81
2.....	60	50	60	50	83.33	83.33
3.....	60	48	60	38	80.00	63.33

of twenty-four hours in converting the dust into a bordeaux coating brought about a material decrease in the adhesiveness of the copper. In comparing the data in the two tables, it appears that, although about twice as much dust was retained by wet foliage as by dry foliage, the dust was slightly more adhesive when the leaves were moistened after the application. This slight difference was probably due to the better distribution of the material on the dry leaves. In order to obtain further information on this question, glass slides were dusted, one series being sprayed uniformly with water prior to the application, and the other being sprayed after the application. The percentage of copper that remained after the artificial rainfall was as follows:

Experiment 1. Slides moistened before dusting.....78.26 per cent
Slides moistened immediately after dusting.80.70 per cent
Slides moistened 24 hours after dusting....82.60 per cent
Experiment 2. Slides moistened before dusting.....85.33 per cent
Slides moistened immediately after dusting.86.66 per cent
Slides moistened 24 hours after dusting....84.50 per cent

Since there is no significant difference between the values in either of the experiments, it is doubtful whether the time of wetting the dust has any influence on its adhesiveness, as long as a good distribution of material is insured. It is obvious, however, that if the foliage is dusted when dripping wet or when holding large drops of water, the distribution of the dust is likely to be not so even as on dry leaves.

Field experiment

During the summer of 1922, an experiment was conducted to determine, under field conditions, the relative adhesiveness of copper-lime dust to wet and to dry foliage. Six plots were dusted with a four-row power machine in the early morning when the vines were wet with dew, and six plots in the early afternoon when the vines were dry; one plot was dusted with a hand duster, in the early morning. A curtain was used when the power duster was operated in the afternoon, to protect the nozzles from the wind. Since copper tests were made before and after each application, beginning with the third, it was possible to determine not only the relative amounts of dust retained by the leaves during the applications, but also the relative degrees of washing between the applications.

The results of the individual copper tests are given in tables 4 and 8.

TABLE 8. RESULTS OF COPPER TESTS MADE ON LEAVES DUSTED WHEN DAMP AND WHEN DRY WITH COPPER-LIME DUSTS CONTAINING 8½ AND 10 PER CENT OF COPPER; POWER DUSTER USED FOR THE DRY FOLIAGE AND HAND DUSTER FOR THE DAMP FOLIAGE

(See also table 4 for data on copper tests made on leaves dusted with power duster when damp)

Applications		Pounds of copper applied per acre		Milligrams of copper on 100 grams of green leaves					
				Dusted when damp			Dusted when dry		
Date	No.	To damp foliage	To dry foliage	Before application	After application	Amount retained	Before application	After application	Amount retained
June 10	1	3.0	3.33	.....	.....	.....	.....	.....	.....
15	2	2.5	3.19	.....	40.5	.....	.....	Trace	.....
22	3	3.0	3.70	10	28.0	18	Trace	15	14
28	4	4.0	4.00	15	32.0	17	Trace	15	14
July 5	5	3.5	3.00	20	48.0	28	4	12	8
13	6	3.6	4.10	22	62.0	40	7	18	11
18	7	3.0	3.20	57	75.0	18	8	15	7
24	8	4.1	4.85	61	121.0	60	12	30	18
27	9	3.0	3.50	102	130.0	28	25	39	14
August 3	10	3.5	3.50	87	120.0	33	16	26	10
7	11	2.5	2.10	112	139.0	27	20	34	14
14	12	5.0	6.00	121	171.0	50	28	40	12
19	13	4.0	4.10	159	224.0	65	40	75	35
22	....	.....	.....	130	.....	.....	40	.....	.....

The data recorded in table 8 are for foliage dusted when damp with the hand duster, and foliage dusted when dry with the power machine. The data for the tests made with the power machine on wet foliage, in the same experiment, are given in table 4 (page 13), together with the data for the sprayed plants. The plants that were dusted when the leaves were wet retained more than twice as much dust as did those that were dusted when the leaves were dry. Although a greater percentage of the copper retained by the wet leaves was washed off between applications, yet the amount accumulating as the season progressed was much greater, due to the greater quantity of dust that was retained during the applications. At the time when the last copper test was made, there was three times as much copper on the foliage that received applications when the vines were wet, as on that which was dusted when dry. The results showing the relative amounts of dust retained compare favorably with those of the greenhouse experiments, in which it was found that the damp foliage retained a little more than twice as much copper as did the dry leaves. According to the experiments with potted plants in the greenhouse, the coating that resulted from a copper-lime dust set with a thorough spray of water either immediately after the application to dry foliage or twenty-four hours later, was as resistant to washings as was the covering that resulted from an application on damp foliage. Under field conditions, there was a greater percentage loss of dust from foliage dusted when dry than from foliage dusted when wet, due probably to the fact that in some cases the dust would be blown or washed from the dry dusted foliage before it had time to set.

In comparing the data for the relative adhesion of the dust when applied with the power duster and with the hand machine (table 9), it is seen that

TABLE 9. SUMMARY OF DATA SHOWING THE RELATIVE ADHESION OF A COPPER-LIME DUST TO WET FOLIAGE AND TO DRY FOLIAGE

Average number of pounds of copper applied per acre at each application		Average number of milligrams of copper on 100 grams of green leaves for each pound of copper applied per acre					
		Retained during the application			Washed off before the following application		
With power duster	With hand duster	Wet foliage, power duster	Dry foliage, power duster	Wet foliage, hand duster	Wet foliage, power duster	Dry foliage, power duster	Wet foliage, hand duster
3.82	3.56	8.98	3.87	9.62	6.89	2.96	6.85
Increase for wet foliage over dry, power duster		5.11 ± 0.63			3.93 ± 0.98		
Increase or decrease with hand machine over or under power duster, wet foliage...		+0.64 ± 0.29			−0.04 ± 4.33		

slightly more dust was retained by the plants dusted with the hand machine and that there was practically no difference in the amount of copper that was lost between applications. Although the hand-dusted plot was treated always after the other plots in the experiment, and, on a few days, when the vines were drying off rapidly, yet it is not surprising to find that an equally efficient covering was secured throughout the season with the hand duster, because the distribution of dust from the latter was far superior to that obtained with the power machine.

COMPARISON OF VARIOUS COPPER DUSTS ON WET FOLIAGE

After studying the adhesiveness of the copper-lime dust in comparison with bordeaux mixture and when applied to damp and to dry foliage, the question arose regarding the relative efficiency of this dust, as correlated with this particular property, and of other dusts that do not contain their copper in the form of dehydrated copper sulfate.

With reference to the physical properties and fungicidal values of bordeaux powders and pastes, Lutman (1916) reports that the pastes are practically unchanged from the freshly prepared condition, and he considers them as valuable in fungicidal properties as the freshly prepared bordeaux mixture. The powders, on the other hand, he considers practically worthless as fungicides, since the precipitation membranes of the bordeaux preparation are changed, during the drying process, from the colloidal state into dry, shriveled forms, which, when re-wet, failed to regain any of their former covering and adhesive properties.

For the experiments to study this question, two dusts were chosen. One of these, known as "Copper-carb,"[7] was mixed with sufficient hydrated lime to represent the desired percentages of metallic copper. The other mixture was Sanders' green copper-arsenic dust,[8] which also does not contain copper in water-soluble form. This dust, as it was employed in these experiments, contained 9 per cent of metallic copper and 5 per cent of arsenic. It is very finely divided, and is guaranteed by the manufacturer to pass through a screen with 300 meshes to the inch.

When the copper-carbonate dust is applied to a wet surface, apparently no chemical change takes place. The colloidal membranes characteristic of bordeaux mixture and of copper-lime dust are not formed, nor are they formed when the green copper-arsenic dust is wetted. In the latter mixture a few membranes are generally present, as distinguished by the potassium-ferrocyanide stain, but they are not highly hydrated or gelatinous.

Greenhouse experiments

Both greenhouse and field trials were included in the comparison of the two proprietary dusts and the copper-lime dust. In the greenhouse, both on glass slides and on potato foliage the copper-lime dust proved superior to both the other mixtures, the copper-carbonate dust exhibiting the lowest degree of adhesiveness of the three. When equal weights of the three dusts,

[7] Copper-carb is a proprietary dust, containing 18 per cent of metallic copper in the form of carbonate, manufactured by the Corona Chemical Division, Pittsburgh Plate Glass Company, Milwaukee, Wisconsin.

[8] This is a proprietary dust, the formula for which was originated by G. E. Sanders, of Nova Scotia. The dust was supplied by the Dosch Chemical Company, of Louisville, Kentucky. As the writer understands it, during the initial steps in the preparation of the dust the three constituents—copper sulfate, calcium arsenate, and stone lime—are mixed and the lime is started to slaking.

containing equivalent percentages of copper and arsenic, were applied to the plants, approximately equal amounts were retained by the foliage in each case, either when the plants were wet or when they were dry. In table 10 are given data which represent the percentages of copper that remained

TABLE 10. RESULTS OF COPPER TESTS TO DETERMINE THE RELATIVE ADHESIVENESS OF DIFFERENT KINDS OF COPPER DUSTS TO POTATO FOLIAGE AND TO GLASS PLATES IN THE GREENHOUSE

Experiment no.	Per cent of copper in dusts	Per cent of total copper remaining after artificial rains					
		When copper-lime dust containing dehydrated copper sulfate was applied		When Sanders' green copper-arsenic dust with insoluble copper was applied		When Copper-carb diluted with hydrated lime was applied	
		Leaves	Glass	Leaves	Glass	Leaves	Glass
1	6	73.10	77.6	66.00	62.00	31.0	40.8
2	9	71.50	77.0	50.60	52.58	35.0	38.0
3*	9	80.25	86.8	69.91	75.21	.....	.....
4	6	88.24	.....	63.34	.....	.....	.....

*In this experiment the plants and the glass plates were dusted when dry, and were subsequently wetted.

after washings. In each experiment the copper-lime dust — that is, the one that produces colloidal copper-membranes when wet — exhibited the greatest degree of adhesiveness. The green copper-arsenic mixture, which is actually a kind of bordeaux powder, proved superior to the copper-carbonate dust, due probably to its finer texture. Furthermore, the copper-lime dust that contained 6 per cent of copper showed about the same degree of adhesiveness as did the one containing 9 per cent.

Field experiment

In 1922 a field experiment on Green Mountain potatoes was conducted, in which the following dusts were compared: copper-lime dust; copper-lime dust with "Kayso"[9]; copper-lime dust in which part of the hydrated lime was replaced by gypsum; and Copper-carb diluted with hydrated lime. Each mixture contained 10 per cent of metallic copper. Eleven applications were made, at intervals of about seven days and, with one exception, when the vines were thoroughly wet from dew or fog. Although there was no attempt to apply definite quantities of the dusts per acre, it was the intention to put on equal amounts in the different plots. Due to the irregularity in the rate of feeding with the mixtures containing gypsum and Copper-carb, however, the applications of those dusts varied more or less in amount from that in the other two dusts, and were usually greater. Each treatment included one two-row plot.

[9] Kayso is a casein spreader, furnished by the California Central Creameries, of New York City, and consisting of a mixture of one part of casein and two parts of hydrated lime.

The results of the individual copper tests, together with the accompanying averages, are given in table 11. The figures for the copper determination show that practically equivalent amounts of copper were retained in the copper-lime dusts with and without the casein spreader,

TABLE 11. RESULTS OF COPPER TESTS TO DETERMINE THE RELATIVE ADHESIVENESS OF DIFFERENT KINDS OF COPPER DUSTS APPLIED WITH A HAND DUSTER TO DAMP FOLIAGE IN THE FIELD

Dust applications		Milligrams of copper on 100 grams of green leaves on foliage dusted with							
		Copper-lime dust (10 per cent of copper)		Copper-lime dust with Kayso sticker (10 per cent of copper)		Copper-lime dust with gypsum as a diluent (10 per cent of copper)		Copper-carb with lime (10 per cent of copper)	
Date	No.	Before application	After application	Before application	After application	Before application	After application	Before application	After application
June 29	4	15	26	18	30	25	50	12	45
July 7	5	18	51	15	46	25	40	6	62
15	6	42	55	40	55	30	55	14	25
20	7	48	103	50	110	51	112	15	60
25	8	88	122	94	119	100	131	32	62
August 2	9	89	125	90	138	85	120	40	80
10	10	117	179	128	188	105	200	40	112
17	11	169	232	175	246	190	275	78	150
22	....	214	.....	228	.....	254	.....	100	.....
Average retained		38.38		40.25		46.50		44.88	

Average percentage of total copper present after each application, that was washed from the foliage before the following application:

Copper-lime dust	15.32
Copper-lime dust with Kayso	16.57
Increase over copper-lime dust	1.25 ± 1.80
Copper-lime dust with gypsum	19.15
Increase over copper-lime dust	3.83 ± 1.92
Copper-carb with lime	49.99
Increase over copper-lime dust	34.67 ± 5.12

and the data in the tabulated averages indicate that there was no significant difference in the rate of washing. It seems, therefore, that the Kayso had no appreciable effect on the adhesiveness of the copper-lime dust.[10] The copper-lime mixture containing gypsum for a partial diluent showed no marked increase in the degree of washing over that for the dust without gypsum, even though the rate of application was considerably higher, as is indicated by the average number of milligrams of copper retained by the two dusts. The Copper-carb, on the other hand, which was applied at approximately the same rate as the gypsum dust, proved decidedly less adhesive to the foliage than did the other dusts. There was an average increase in the percentage of washing from the foliage, of 34.67 ± 5.12, over that for the copper-lime dust, which is undoubtedly a significant difference. In calculating the percentage of copper that was washed from

[10] When Kayso was added to bordeaux mixture, on the other hand, the spreading qualities of the spray were greatly increased, resulting in a continuous coating, or layer, of uniform thickness on the upper surface of the leaves and on the stalks and petioles. Copper tests made throughout the season, however, showed that there was no additional copper retained by the leaves during applications, and that there was no less washing from the foliage between applications.

the leaves between applications, the total amount present after each application was considered as 100 per cent. The results for the copper-carbonate dust agree rather closely with those obtained in dusting plants in the greenhouse, and indicate that such a dust, whose copper is in an insoluble form, does not possess as high a degree of adhesiveness when applied to wet foliage as one whose copper is converted into colloidal membranes.

RELATIVE TOXICITY OF BORDEAUX MIXTURE AND COPPER-LIME DUST TO PHYTOPHTHORA INFESTANS

The relative adhesiveness of copper-lime dust and of bordeaux mixture having been considered, attention was next turned to their relative fungicidal value. An attempt was made to determine the quantity of copper that was necessary in the fungicides to prevent germination and infection with zoospores of *Phytophthora infestans* (Mont.) de Bary.

In his publication of 1914, Butler (1914) included the results of some spore-germination tests conducted for him by Melhus. Melhus sprayed glass slides with bordeaux mixture in which the ratio of copper sulfate to calcium oxide varied between 5 and 0.5. After the slides had been allowed to stand for twenty-four hours, drops of spore suspensions containing the sporangia of *P. infestans* and *P. viticola* were applied. Melhus found that when tap water was used in preparing the mixtures, a mixture containing 0.5 per cent of copper sulfate was not toxic, but that when distilled water was employed, all of the mixtures, regardless of the ratio of copper sulfate to calcium oxide, were toxic at 0.0625 per cent of copper sulfate. The amount of copper present per unit of surface was not given.

In 1916, Butler (1916) offered further data indicating that the efficiency of unit copper is the same in neutral, alkaline, and acid bordeaux mixtures. When mixtures with ratios of copper sulfate to calcium oxide of 1:0.3, 1:1.5, and 1:2, and containing 1.97 milligrams of copper in 100 cubic centimeters, were sprayed on glass slides to give 0.075 milligram of copper to 1000 square centimeters, the coatings were not toxic to the direct[11] germination of the sporangia of *P. infestans*. Mixtures with ratios of 1:0.2, 1:0.3, and 1:2, and containing 3.95 milligrams of copper in 100 cubic centimeters, and representing 0.15 milligram of copper to 1000 square centimeters, prevented germination. The amount of copper to 1000 square centimeters, however, was designated as "indicative only." These germination tests also were conducted by Melhus.

Melhus (1915), in using the method described in the preceding paragraphs, presented data which showed that bordeaux mixtures containing copper sulfate and calcium oxide in the ratios of 1:1 and 1:2 prevented indirect germination of sporangia of *P. infestans* when they were diluted to contain about 0.015 per cent of copper sulfate, and permitted germination when they were represented by one-half that concentration. The amount of copper per unit of surface area was not stated.

Regarding the amount of copper in a bordeaux mixture required to control late blight of potatoes in the field, Butler (1920) reported that a 1-per-cent mixture of the ratio "1:05" (1:0.5?) is superior to a 1-per-cent

[11] By "direct" germination is meant the production of one or more germ tubes by the spore. "Indirect" germination refers to germination by the formation of zoospores.

mixture of the ratio 1:1, and that a 2-per-cent mixture of the ratio "1:05" (1:0.5?) applied at intervals of two weeks is superior to either of the 1-per-cent mixtures applied weekly. Bordeaux paste and Pyrox were less effective than freshly prepared bordeaux mixture. Butler estimated, by correlating the amounts of copper added during the season with the degree of control, that the quantity of copper which should be applied per acre in a season, in order to prevent losses from *P. infestans*, lies between twenty-four and twenty-six pounds. Unfortunately, the relative amount of late blight in the tops, and the comparative yields of the plots under different treatments, were not mentioned. Only the percentage of rotted tubers at digging time was considered in determining the merits of the different fungicides and of the methods used in applying them.

Cook (1920), in comparing the Pickering sprays with bordeaux mixtures for late-blight control, found that the Pickering spray containing the equivalent of 0.7 per cent of copper sulfate adhered as well to the foliage and controlled late blight as effectively as a 5–5–50 bordeaux preparation. The yield was the same in both cases. Cook concluded that the amount of copper necessary to control late blight might be reduced 44 per cent by using Pickering's spray.

It is evident from the foregoing citations that under laboratory conditions the quantity of copper in bordeaux form necessary to prevent sporangium germination in *P. infestans* is exceedingly low. Melhus (1915), in referring to this point, makes the following statement: "The most efficient 2-per-cent Bordeaux mixtures contain nearly 200 times as much copper sulphate as is needed to prevent indirect germination of the spores of *Phytophthora infestans*. This suggests that a reduction in the amount of copper sulphate can be made in Bordeaux mixture used for the control of Phytophthora if these laboratory tests are a true representation of conditions existing in the open." The results of Butler's field experiments previously referred to, in connection with which Butler recommended from 24 to 26 pounds of copper sulfate in a season for late-blight control, do not seem to bear out the probability suggested by Melhus.

The writer was unable to find any reports on investigations conducted for the purpose of determining the amount of copper per unit of leaf area, in the form of bordeaux mixture or of any other copper fungicide, which is necessary to furnish protection to the potato plant against infection from the late-blight fungus. In order to gather some information concerning this question, experiments were conducted with the object of determining the amount of copper in the form of bordeaux mixture that is required to prevent germination of zoospores in the laboratory, and the amount necessary to prevent infection in the greenhouse. A copper-lime dust was included in the experiments in order to compare its fungicidal value with that of the bordeaux preparation. An undetermined species of Phytophthora was included with *Phytophthora infestans* in the germination tests. The following methods were employed.

In the spore-germination experiments, glass slides, each with an area of 15.5 square centimeters, were dusted with a copper-lime dust containing 9 per cent of copper, and were sprayed with various dilutions made from a 4–4–50 bordeaux mixture prepared from tap water, freshly hydrated lime, and a stock solution of chemically pure copper sulfate in distilled water. The copper-sulfate solution had previouly been analyzed for copper content.

The greatest precautions were observed in the attempt to apply an equal amount of spray to each slide, and equal amounts of dust to the dusted slides. Preliminary copper tests were made in order to determine the uniformity of the copper coatings on the several slides in a series, before germination tests were undertaken. It was found that by dusting the dry slides and wetting them afterward with a fine spray of water, a better distribution of material could be obtained on a single slide than could be obtained by dusting slides which had previously been sprayed with water. Both the dusted and the sprayed slides were allowed to stand for twenty-four hours, after which period each series was divided into two lots. One lot was employed in the germination tests, and the other was used for the copper determinations.

The spore material in the germination tests included fresh sporangia from diseased leaves of potted potato plants growing in the greenhouse, in the case of *Phytophthora infestans*, and sporangia taken from agar cultures, in the case of the unknown species. The method of obtaining zoospores was essentially that described by Melhus (1915). Only cultures containing large numbers of motile zoospores were used. From eight to twelve drops of the spore suspension were placed on a slide, which was then incubated at 23° C. for from five to ten hours. If unsatisfactory germination occurred on the control slides, the entire experiment which involved the use of the particular spore material concerned was discarded. On the treated slides, if germination occurred in 75 per cent or more of the drops the results were considered positive; if there was no germination, or only a trace, the results were listed as negative.

The method of spraying the slides with different dilutions of the bordeaux mixture, accompanied by an accurate determination of the copper on the sprayed surface, was employed only in a sufficient number of trials to prove beyond question that such a method might be used to advantage.

The amount of copper per square meter (as determined by the colorimetric method) which was necessary to prevent germination of the zoospores, was checked against the amount which proved toxic when measured quantities of the same dilutions of bordeaux mixture were pipetted upon slides. In the latter case, the amount of copper per unit area of surface was controlled, while in the former it had to be determined. Since it was possible to obtain like results with the same amount of bordeaux copper, whether the mixtures were sprayed uniformly on the slide or spread out in a thin film, the latter method was adopted for a majority of the germination experiments. By using this method, the more or less tedious procedure involved in the copper determinations was eliminated.

In order to utilize the " controlled " method to the best advantage, it was necessary to select glass slides on which the diluted bordeaux mixture could be spread out into a film of uniform thickness.[12] Before the bordeaux dilutions were pipetted on the slides, they were first sprayed into a vessel, by the use of a small hand sprayer, in order that any rupturing of the membranes such as might occur during spraying would be simulated. One-tenth of a cubic centimeter of the dilution was then pipetted on a slide and spread out evenly, and the slide was placed on a level surface to

[12] For this purpose, a grade of glass slide was used which on being heated over a flame underwent surface cracking to the extent that the effect resembled etching. It was thereby possible to spread a few drops of the spray mixture evenly over the surface.

dry. After a period of twenty-four hours, drops of spore suspensions were placed on the slides and the slides were placed in the incubator.

For the infection experiments in the greenhouse, three varieties of potatoes were used—Irish Cobbler, Green Mountain, and Bliss Triumph. Since the amount of copper found to be necessary for control of the blight was the same for all three, no further consideration is given to the separate varieties in discussing methods and results. Plants of the same age and size were selected for each experiment, and there was little difference in the size of the plants in all of the experiments. The fungicides were the same as those used in the spore-germination tests. Before the plants were treated, a few leaves were removed from each plant in order that the remaining leaves might be better exposed to the application of the fungicides. To insure the application of equal quantities of material to the different leaves of a plant and to the leaves of the other plants in the same series, only one side of one or two leaves was sprayed or dusted at a time. By this method, each side of every leaf received the same amount of the fungicide. Copper tests made from preliminary trials showed that remarkably uniform amounts of copper per square decimeter were applied to the different leaves of a plant or of a series of plants. As a rule, each inoculation series sprayed with a given dilution of bordeaux mixture consisted of four plants, two for copper tests and two for inoculations. In all of the experiments, inoculations were made with zoospores on both the upper and the lower surface of the leaves.

The quantity of copper per square meter of leaf surface was determined by measuring the area of the leaves with a planimeter, and then dissolving the copper from the leaves with the nitric-acid wash. The volume of the wash was reduced to a minimum, only two or three leaves being treated at one time, in order that the color developing in the wash might be sufficiently intense to furnish a fair comparison with the standards.

SPORE-GERMINATION TESTS

The results of the germination tests with bordeaux dilutions (table 12) indicate that the amount of copper required to inhibit germination of zoospores is even less than the amount reported by Butler (1916) as necessary

TABLE 12. RESULTS OF EXPERIMENTS TO DETERMINE THE AMOUNT OF COPPER IN BORDEAUX MIXTURE NECESSARY TO PREVENT GERMINATION OF ZOOSPORES OF PHYTOPHTHORA INFESTANS ON GLASS SLIDES

Experiment no.	Control	Concentration of bordeaux mixture: 1 cubic centimeter (2.47 milligrams of copper) diluted to							
		512 cc		1024 cc		2048 cc		4096 cc	
	Average length of germ tubes (microns)	Milligrams of copper per square meter	Average length of germ tubes (microns)	Milligrams of copper per square meter	Average length of germ tubes (microns)	Milligrams of copper per square meter	Average length of germ tubes (microns)	Milligrams of copper per square meter	Average length of germ tubes (microns)
1.....	100	0.311	0	0.155	12	.....	.....	0.0357	100
2.....	85	0.311	0	0.155	16	0.0775	60	0.0357	80
3.....	120	0.311	0	0.155	25	0.0775	40	0.0357	100
4.....	85	0.311	.....	0.155	0	0.0775	45	0.0357	75
5.....	175	0.311	0	0.155	40	0.0775	100	0.0357	100

to prevent indirect germination of the sporangia of the same fungus. Butler gives the inhibiting concentration as equivalent to 1.15 milligrams per square meter, and the nearest concentration that is not toxic as 0.75 milligram per square meter. In the present investigations, the inhibiting point might be considered a concentration of 0.311 milligram of copper per square meter, and the nearest point not toxic as 0.155 milligram. This difference is not surprising, since sporangia were under consideration in Butler's work, and zoospores in the present work.

Throughout the germination experiments the unknown species of Phytophthora, which makes a rather vigorous growth on oatmeal agar and develops oospores abundantly on the same medium, was more resistant to the toxic action of the bordeaux mixture than was *Phytopthhora infestans*. The concentration of copper required to inhibit germination of its zoospores was 1.08 milligrams per square meter, and in the control cultures its germ tubes were at least twice as long, after a given incubation period, as those of *Phytophthora infestans*.

Fortunately, it was through the use of this undetermined species of Phytophthora in the germination tests that a bare possibility was realized in comparing the copper-lime dust with the bordeaux mixture for the relative toxicity of unit copper contained. It is possible to dilute the liquid bordeaux mixture at will, thereby obtaining any strength desired. A dust, on the other hand, is difficult to dilute. The only feasible means of applying an extremely light application of a copper-lime dust containing, for example, 9 per cent of copper, is to allow the dust cloud discharged from the nozzle to strike the slide in a highly dispersed condition. Even when such a method is used, the particles of copper are not broken up and multiplied many times, either before they reach the surface to be dusted or after they have become wet on the surface, as is the case with a highly diluted bordeaux mixture. It was found that with the lightest application of dust on a slide which represented a uniform covering of the surface, the inhibiting point of zoospore germination for *Phytophhtora infestans* could not be passed. In other words, an application, while thoroughly covering the surface, could not be made light enough to permit germination. It was possible, however, to make such a light application in the germination tests involving the undetermined species of Phytophthora. The range of inhibition varied between 6.21 milligrams and 3.10 milligrams per square meter. At all concentrations below 3.10 milligrams, germination occurred. Since no germination in this species was obtained on the slides with the bordeaux mixture containing 1.01 milligrams of copper per square meter, it appears that with the dilution of the bordeaux mixture representing that concentration of copper (1 cubic centimeter of 4–4–50 diluted to 144 cubic centimeters) the liquid bordeaux mixture is from three to six times as toxic, per unit of copper, as is the dust. It seems probable, however, that if such comparisons could be successfully carried out with much lower dilutions of bordeaux mixture—say with a $\frac{1}{2}$–$\frac{1}{2}$–50 or a 1–1–50 concentration, in which the colloidal membranes approach nearer in form and character to those of the dust—even this slight difference in relative toxicity of the two fungicides might be further reduced.

INFECTION EXPERIMENTS

The results of the greenhouse experiments (table 13) indicate, as a whole, that about twice as much copper in the form of a dilute bordeaux mixture is necessary to prevent infection by zoospores, as is required to inhibit germination on glass slides. The correlation of the two amounts is indeed

TABLE 13. RESULTS OF EXPERIMENTS TO DETERMINE, UNDER GREENHOUSE CONDITIONS, THE AMOUNT OF COPPER IN BORDEAUX MIXTURE NECESSARY TO PREVENT INFECTION OF POTATOES BY ZOOSPORES OF PHYTOPHTHORA INFESTANS

Concentration of bordeaux mixture sprayed upon the leaves: 1 cubic centimeter (2.47 milligrams of copper) diluted to

64 cc		128 cc		256 cc		512 cc		1024 cc	
Milligrams of copper per square meter	Degree of infection	Milligrams of copper per square meter	Degree of infection	Milligrams of copper per square meter	Degree of infection	Milligrams of copper per square meter	Degree of infection	Milligrams of copper per square meter	Degree of infection
1.9	None	.....	.....	0.470	Light	0.240	Medium	0.120	Heavy
1.6	Trace	0.800	None	0.400	Medium	0.200	Heavy	0.100	Heavy
1.5	None	0.750	None	0.375	Light	0.185	Heavy	0.097	Heavy
1.2	Trace	0.600	Trace	0.300	Medium	0.150	Heavy	0.075	Heavy
1.3	None	0.660	None	0.330	Light	0.165	Light	0.082	Heavy
1.25	None	0.625	Trace	0.312	Trace	0.156	Medium	0.078	Heavy
0.93	None	0.460	Trace	0.230	Medium	0.115	Heavy	.....	.....

striking, and suggests that when the comparison is made in the range of such high dilutions there is, after all, a very slight difference in the amounts of copper that are necessary for control in the two cases.

In determining the amount of copper in the copper-lime dust necessary to furnish protection to foliage, the same difficulty was found in the inoculation experiments as in the germination tests. In all trials when the applications made were extremely light, yet heavy enough to produce a uniform distribution on the leaves, and the dust was allowed to set by the application of a light spray of water, no infection resulted when the plants were inoculated. The leaves of a plant dusted in that manner showed from 10 to 15 milligrams of copper per square meter. These values, although small indeed and not representing the lower point of toxicity, are about 15 to 20 times higher than the lower limit for protection with a diluted bordeaux mixture.

If the results of the infection experiments in the greenhouse were applied to field conditions, and if all parts of the potato plant could be kept covered with the bordeaux preparation, a very small quantity of copper would be sufficient to insure protection against the late-blight organism. While the matter of loss from the foliage due to washing by rains and heavy dews or fogs must be taken into account, yet it has been shown that if the dust or the spray is applied in such a manner as to give a thorough distribution of the fungicide, only about 15 to 25 per cent is lost during a vigorous washing. Judging merely from the greenhouse experiments, it would seem advisable to emphasize the importance of keeping all parts of the plant covered by a thorough distribution of the material with frequent applications, rather than the encouragement of heavy applications of copper at longer intervals.

The question of insect control, however, might necessarily modify the requirements for general spraying operations. There is need of further experimentation in the field to determine more accurately the amount of copper required in a bordeaux mixture and other fungicides used on potatoes, and the frequency of applications necessary to control fungous diseases and insect pests.

EXPERIMENTS WITH DUSTS AND SPRAYS[13]

Prior to 1920, the use of Sanders' copper-lime dust had received only scant attention aside from the experimental work conducted in Nova Scotia and New Brunswick, Canada, where the fungicide was developed. In 1918, Sanders and Kelsall (1918) published an article on this dust, which had then been only recently developed by Sanders, giving directions for preparing the mixture and reporting some results on dusting and spraying experiments with potatoes. Concerning those experiments, they stated that a copper-lime dust containing 5 per cent of copper and 2 per cent of arsenic controlled late blight effectively at Fredericton, the dusted plot yielding 396 bushels per acre as against 407 bushels for the average of 24 plots sprayed with 4–4–50 bordeaux mixture and 238 bushels for the check plots. At Truro, the dusted plot yielded 744 bushels per acre, the sprayed plot 652 bushels, and the check plots 550 bushels. In two other experiments Sanders and Kelsall reported that the dusted plots produced as high yields as did the sprayed plots. They expressed the opinion, however, that there was a greater waste of material in dusting than in spraying.

In a further report on the new copper-lime dust, Sanders and Kelsall (1920) state that at Fredericton the dust again gave yields as high as those obtained with bordeaux spray, but the control of late blight was not perfect unless the dust mixture contained 5 per cent of metallic copper or more. They reported that a 7.5–2 mixture — that is, one containing 7.5 per cent of copper and 2 per cent of arsenic — gave better protection against late blight and rot than did a 5–2 dust. They were of the opinion that calcium arsenate is much more effective in the dust than in a spray mixture.

In 1919 the Department of Plant Pathology at Cornell University, through two of its temporary field laboratories, conducted preliminary experiments in potato dusting and spraying. One of these laboratories was located in Dutchess County, New York, and the other in Nassau County. Promising results were obtained in each county with the copper-lime dust, and in the following year experiments were conducted in five field laboratories by industrial fellows. In each county, however, potato dusting was only one of several projects undertaken, and experiments were planned and carried out in a preliminary way. Again results were obtained that appeared encouraging for the dust in the control of late blight and flea beetles.

In 1921 the fellowship investigations were continued in three of the field laboratories. In general, the results were similar to those obtained

[13] The studies reported in this bulletin were terminated in July, 1923, and the manuscript was then placed in essentially its present form. Due to unavoidable delays, it has not been possible to publish it at an earlier date. In the interim, several publications on the relative merits of sprays and dusts for potatoes have appeared. In addition to an article by F. C. Stewart and P. J. Parrott (Dusting vs. spraying. *In* Experiments with potatoes, New York [Geneva] Agricultural Experiment Station, Bul. 518:3-29. 1924), in which certain references to recent literature are to be found, the publications of Martin (1924), Dimock (1924), and Wallace (1924), should be noted. Because of the availability of these articles, and the further delay in publishing this paper if a review of them were incorporated herein, it is felt that this brief note is sufficient.—L. M. MASSEY.

during the preceding summer.[14] Only in Suffolk County and Washington County were the investigations confined to potato protection, and a consideration of those experiments is included in this paper.

The experiments conducted in Suffolk County extended over a period of three years and were located at Bridgehampton and Southampton, two potato-growing sections on the south shore of Long Island. During the summer months the weather conditions there are, as a rule, favorable for the development of late blight. The cool nights with heavy dews and fogs, alternating with moderately warm, windy days, furnish ideal conditions for infection. Flea beetles are generally present throughout the growing season, and aphids become destructive in certain years.

In the sections of Washington County where additional experiments were conducted in 1921, the days were generally very warm and dry, and the nights were only moderately cool and with less moisture than in Suffolk County. During that particular summer, no traces of late blight were observed in any of the experiments. Injuries from tipburn and insects, however, constituted an important factor in the experiments.

COPPER-LIME DUST COMPARED WITH BORDEAUX MIXTURE

Experiments of 1920

In 1920, experiments of a preliminary nature were undertaken to compare lime-bordeaux, "bordeaux-lead,"[15] and sal-soda-bordeaux, with Sanders' copper-lime dust in the control of potato diseases and pests. Sal-soda-bordeaux is the spray mixture commonly used in the Bridgehampton potato section, while the use of lime-bordeaux predominates at Southampton. The sprayers and spray materials used were those ordinarily employed by the three growers who cooperated. The duster used in each case was a Niagara hand blower-gun. In experiment 1, a Union Leader power machine carrying from 180 to 200 pounds pressure was used. In experiments 2 and 3, traction sprayers furnishing about 150 pounds pressure were employed. Each sprayer was equipped with one nozzle to a row. No attempt was made to apply equal amounts of copper in the different fungicides under comparison. A record was kept, however, of the amount of materials used on the plots of the three experiments, and this is included, together with the size, number, and yield of the plots, in tables 14 and 15. All dust applications were made early in the day while the vines were still moist from dew or fog. The spray applications were made later in the same day, on dry foliage. The first two applications in each experiment contained poison for bugs. The season as a whole was highly favorable for the development of late blight, and was further characterized by general injury from flea beetles and tipburn.

Experiment 1 (Farm of H. T. Fahy, Bridgehampton, New York).—The potato field used in the first experiment was 48 rods long. The arrangement of the plots is indicated in table 14. The sprayer used was an engine-power Union Leader carrying six nozzles, one to a row.

Late blight, the only fungous disease of any consequence, made its appearance in the plots about June 25. The infection spread rapidly in

[14] The dusting and spraying results for 1920 and 1921 were summarized in mimeographed reports and distributed by the Department of Plant Pathology.

[15] See footnote 5, page 9.

TABLE 14. YIELD OF GREEN MOUNTAIN POTATOES DUSTED AND SPRAYED IN EXPERIMENT 1, 1920

(Farm of H. T. Fahy, Bridgehampton, New York)

Fungicides	Rate of application per acre	Number of rows in plots	Number of applications	Yield, in bushels per acre	Increase or decrease in yield over or under the two nearest soda-bordeaux plots	
					Bushels per acre	Per cent
Soda-bordeaux, 6-7-50	75 gals...	12	10	238	.....	.....
Copper-lime dust:						
6 per cent of copper.	48 lbs....	12	10	287	+37.5	+15.00
6 per cent of copper.	48 lbs....	4	6	252	−5.3	−2.03
Soda-bordeaux, 6-7-50	75 gals...	12	10	265	.....	.....
Bordeaux-lead dust:						
6 per cent of copper.	48 lbs....	8	10	267	+15.4	+6.12
6 per cent of copper.	48 lbs....	4	6	223	−20.6	−8.45
Soda-bordeaux, 6-7-50	75 gals...	12	10	169*	.....	.....
Check	.....	6	.....	103	−118.0	−53.40
Soda-bordeaux, 6-7-50	75 gals...	12	10	209	.....	.....
Lime-bordeaux, 6-6-50	75 gals...	12	10	236	+27.0	+12.90

* Owing to the fact that this plot lay in a dead furrow, an interpolated yield of 233 bushels was assigned to it in comparing its yield with that of the adjacent plots.

the control plot, where the plants died at least three or four weeks earlier than did the dusted vines, due to late blight combined with injuries from tipburn and flea beetles. Only a light and scattered infection was present at any time in the treated plots, but it was more general in the soda-bordeaux plots than in the others. Injury from flea beetles and tipburn was the most severe in the control plot, and the least severe in the lime-bordeaux plot. There was little difference, however, in the degree of injury on the vines in the lime-bordeaux plot and on the dusted vines. The foliage sprayed with soda-bordeaux showed considerable flea-beetle injury and tipburn, and died a few days earlier than did the plants in the other treated plots. Aphids were not abundant in this field. Only a trace of rotted tubers was found in any of the plots

The appearance of the foliage was very much the same in the dusted plots and in those sprayed with lime-bordeaux, but was less vigorous and less free from injury in the soda-bordeaux plots. The coating of dust on the vines dusted with Sanders' copper-lime mixture remained on the foliage longer than did the bordeaux-lead covering, and controlled the flea beetles and the tipburn more effectively. Contrary to the opinion of Lutman (1916), who pronounced bordeaux powders entirely worthless as fungicides, this bordeaux-lead preparation proved almost as effective as the lime-bordeaux spray and the copper-lime dust. The Colorado

potato beetle was equally well controlled with calcium arsenate in Sanders' dust, and lead arsenate in the sprays and in the bordeaux-lead dust. All of the tubers in each plot were dug and weighed.

An increase in the yield over that of the check, due to the different fungicides, was very apparent, even though there was no uniform repetition of the series of treatments. As can be seen from the data in table 14, the soda-bordeaux plots adjacent to the check outyielded the check more than twofold, and those protected with copper-lime dust and lime-bordeaux with the same number of applications produced a marked increase in yield over the corresponding plots sprayed with soda-bordeaux. The acre yield of plots receiving the bordeaux-lead treatment was about 21 bushels less than that for the copper-lime dust. In general the differences in yield of the treated plots corresponded closely with the relative appearance and behavior of the vines during the growing season.

Experiment 2 (Farm of H. S. Ludlow, Bridgehampton, New York).—The second experiment was conducted in a field of Irish Cobbler potatoes less than a mile from the farm where the first experiment was located. The sprayer used was a Brown machine carrying seven nozzles, one to a row.

Early blight became severe in the untreated plot, but developed only slightly on the protected vines. Mere traces of late blight were present on the dusted and on the sprayed foliage, and the infection on the unprotected rows was light as compared with that in the check in experiment 1. Both tipburn and flea-beetle injury were almost absent on the dusted foliage, were very pronounced in the sprayed plot, and were severe in the check. In this test a greater share of the injury to the control vines was not due to late blight, as in experiments 1 and 3, but to the other causes mentioned. A type of leaf injury was observed in the soda-bordeaux plots that was not present in the others, and was attributed to the spray material itself.

From the time when foliage injury became apparent in the sprayed and the untreated plot until the death of the plants in the latter, the vines in the dusted plot appeared larger and healthier. The dusted plants outlived the sprayed vines by at least a week, and those in the control by two or three weeks. All of the tubers in each plot were dug and weighed.

Again the dust made a satisfactory showing, and evidences of its superiority to the soda-bordeaux, as indicated by the relative degrees of protection and by the yields given in table 15, were more marked in this experiment than in experiment 1. It should be noted, however, that considerably more copper was applied in the dust applications of this experiment than in the spray applications.

Experiment 3 (Farm of C. E. Dimon, Southampton, New York).—In the third experiment, Sanders' copper-lime dust was compared with lime-bordeaux spray on Green Mountain potatoes. The arrangement of the plots in the field, which was 25 rods in length, is shown in table 15. The sprayer was a Red Jacket traction machine carrying six nozzles, one to a row. A pressure of about 140 pounds was maintained. The first two applications included poison for the Colorado potato beetle. At digging time, the two outer rows of each plot were discarded in determining the yields.

TABLE 15. YIELD OF DUSTED AND SPRAYED POTATOES IN EXPERIMENTS 2 AND 3, 1920
(Farms of H. S. Ludlow, Bridgehampton, New York, and C. E. Dimon, Southampton, New York)

Experiment no.	Variety	Fungicides	Rate of application per acre	Number of applications	Number of rows in plots	Yield, in bushels per acre	Increase in yield over check		Percentage increase of dust over spray
							Bushels per acre	Per cent	
2	Irish Cobbler	Soda-bordeaux (6–7–50)	50 gals.	6	20	305	34	12.5	.....
		Copper-lime dust (6 per cent of copper)	55 lbs.	5	20	365	94	34.7	19.7
		Check	.....	.....	20	271	.....	.....	.....
3	Green Mountain	Lime-bordeaux (6–6–50)	50 gals.	11	12	345	141	69.1	.....
		Copper-lime dust (6 per cent of copper)	55 lbs.	11	14	370	166	81.4	7.2
		Check	.....	.....	12	204	.....	.....	.....

Late blight developed rapidly and severely in the check, and was the principal cause of the death of the foliage fully a month before the protected plants died. The infection was pronounced at some places in the plot sprayed with lime-bordeaux, but it was decidedly less severe in the dusted rows. A trace of tuber rot was found in the check plot only. Flea beetles and tipburn, although decidedly more injurious to the untreated vines than to those treated, were not a serious factor in this experiment. The dusted plants showed less injury from any of the sources mentioned than did those sprayed with lime-bordeaux, and remained green a few days longer. Considering the protection of the fungicides on the foliage, and the final yields (table 15), entirely satisfactory results were obtained in this experiment with the new dust. Both the dust and the spray gave a large increase in yield over the check.

Summary of results for 1920.— It is apparent, from the results of these three experiments, that both the copper-lime dust and the "bordeaux-lead" powder, when applied to wet foliage, were effective against late blight, flea beetles, and tipburn, and the increase in yield over the checks was about the same in the case of lime-bordeaux and of Sanders' dust. Soda-bordeaux furnished the least protection and produced noticeable injury.

Experiments of 1921

In Suffolk County

In 1921 the experiments for comparing copper-lime dust and bordeaux mixture in Suffolk County were conducted in duplicate, one at Bridgehampton and the other at Southampton. Green Mountain potatoes were used for the tests. There were six replications each, of the dusted, sprayed, and control plots. The arrangement of the plots in the field is shown in table 16. The sprayed plots contained six rows each, and the dusted and control plots four rows each. In experiment 1, at Southampton, the plots were 26 rods in length, and those in experiment 2, at Bridgehampton, were 24 rods in length. The copper-lime dust, that year, was mixed on the farm in a Hunter's Lightning Sifter-Mixer. It contained 6 per cent

TABLE 16. YIELD OF GREEN MOUNTAIN POTATOES DUSTED WITH COPPER-LIME DUST AND SPRAYED WITH BORDEAUX MIXTURE, SUFFOLK COUNTY

(Farms of C. E. Dimon, Southampton, New York, and H. T. Fahy, Bridgehampton, New York)

Treatment	Yield, in bushels per acre	
	Experiment 1	Experiment 2
Dusted	268.2	212.0
Sprayed	238.5	257.0
Check	226.8	169.8
Dusted	256.6	220.8
Sprayed	238.0	237.8
Check	198.0	158.0
Dusted	239.4	216.4
Sprayed	241.7	243.0
Check	217.0	200.0
Dusted	263.8	211.2
Sprayed	270.0	225.6
Check	208.8	157.2
Dusted	250.0	177.6
Sprayed	248.0	235.8
Check	229.0	179.2
Dusted	263.0	199.6
Sprayed	239.5	218.5
Check	243.0	171.0

Experiment 1: Average increase or decrease in yield:

Spray over check	=	+25.53 ± 5.83
Dust over check	=	+35.80 ± 2.85
Spray below dust	=	−10.95 ± 3.84

Experiment 2: Average increase in yield:

Spray over check	=	+63.27 ± 5.60
Dust over check	=	+32.34 ± 5.17
Spray over dust	=	+32.30 ± 3.84

of metallic copper. The rate of application per acre varied from 35 pounds at the beginning of the season, to 60 pounds later when the vines were large and when conditions favorable for late blight existed. The dust was applied at the same rate on both farms—an average of 53 pounds, or the equivalent of 3.18 pounds of copper, per acre for each application.

The bordeaux formula varied from a 5–5–50 to a 7–7–50 mixture, to equal in copper content that of the corresponding dust application. In experiment 1 the average for the season was 3.2 pounds of copper per acre for each application, and in experiment 2 it was 3.07 pounds per acre. All dust applications were made in the early morning while the vines were moist, and the spray applications were made later in the same day after the foliage had dried.

The sprayer used in experiment 1 was a Red Jacket traction machine with six nozzles, one to a row, and carrying from 175 to 200 pounds pressure. Because the machine was fitted with only one nozzle to a row, it was necessary to make a double application each time the plots were sprayed, in order that the amount of copper equivalent to that in the

corresponding dust application would be applied. In experiment 2 an Iron Age traction sprayer was used, carrying twelve nozzles, two to a row, and maintaining a pressure of from 175 to 200 pounds. The duster on each farm was the Niagara power potato duster, equipped for dusting four rows with two nozzles to a row. While this machine was the best that could be obtained at that time, it was not so good as the more recent models. Although metal extensions were attached to the nozzles to protect them from the wet foliage and to aid in the distribution of the dust, and the speed of the fan was increased considerably, yet the machine failed to make as good an application of dust as is possible with a good hand duster. Not only were there unequal amounts of material delivered to the different rows, but the distribution of dust from the individual nozzles was by no means perfect. In order to offset as much as possible the uneven distribution of dust from the four sets of nozzles, the plots were dusted from opposite directions in successive applications. The machine was probably equal to, or better than, the average duster in use at that time.

Twelve applications of both the spray and the dust were made in experiment 1, and eleven applications in experiment 2. On the day of each application, the duster was driven through the check plots in order to equalize any mechanical injury to the vines. At harvest time the two middle rows of each plot were dug and weighed separately.

Late blight, although not so severe as in 1920, was destructive in all of the check plots. The infection was considerably heavier in experiment 1 than in experiment 2. The last two control plots listed in table 16 under experiment 1, suffered less from this disease than did the other four control plots. Only a light infection developed in the dusted and the sprayed plots in either experiment. The spray was slightly more effective in controlling the disease than was the dust. Tuber rot in the treated plots of experiment 2 varied from 1 to 2 per cent, but was less in the check plots due to the fact that the plants in these plots died before conditions conducive to tuber infection appeared. Only a trace of rotted tubers was found in experiment 1.

During the first half of the growing season, a severe infestation of aphids developed in both experiments. The degree of injury was practically the same in all of the treated plots, but was greater in the check plots. Flea-beetle infestation and tipburn were severe during the entire latter half of the growing season. They were more destructive in experiment 2 than in experiment 1. In both fields, however, the untreated plants suffered the most and the sprayed vines the least.

In each experiment the unprotected rows died from late blight, insect injuries, and tipburn, about three weeks earlier than the dusted plots. In experiment 2 the sprayed vines remained green for three or four days longer than the dusted plants. In both fields the bordeaux coating appeared heavier, and more uniform and permanent, on the sprayed plants than on the dusted ones.

In experiment 1, the sprayed plots yielded, on the average, less than the dusted plots by an apparently significant difference[16] (table 16), and in

[16] In calculating the increase in yield of one treatment over another—of sprayed plots over dusted plots for example—it was the practice throughout all of the field experiments where there were two or more replications, to compare the yield of each dusted plot with an interpolated yield between the two nearest sprayed plots. The differences were then averaged, and the probable error was computed as described in footnote 6, page 10.

experiment 2 they produced a significant gain over the dusted plots. The fact that the sprayed vines in experiment 1 received twice the mechanical injury that those in experiment 2 received, accounts undoubtedly in part for the relatively low yield of the sprayed plots in experiment 1 as compared with the yield of the adjacent dusted plots and checks. Furthermore, since the injuries caused by insects and tipburn were more evident in experiment 2, and since the better of the two spray machines was used in that field, the checks and the dusted plots suffered relatively more, in comparison with the accompanying sprayed plots, than did the corresponding plots in experiment 1. These conditions may help to account for the relatively low yield of the sprayed vines in experiment 1, and of the dusted plots in experiment 2 (table 16).

An interesting fact was observed regarding the effect of the fungicides on the size of the plants. In the preliminary experiments of 1920, the dusted vines appeared larger and thriftier than the plants sprayed with soda-bordeaux or those in the check plots, but they were practically of the same size as the vines sprayed with lime-bordeaux. In 1921 horse-drawn machinery was used in both the dusted and the sprayed plots, and the duster was driven through the control plots each time that an application was made on the other plots. During the period from the first to the third application, there appeared to be no appreciable difference in the size and appearance of the plants in the different plots. During the following two weeks, however, the vines in the check plots looked decidedly higher and more vigorous than those in the adjacent dusted and sprayed plots. This condition remained noticeable until the unprotected vines began to die from diseases and insects.

In these experiments the copper-lime dust did not compare so favorably with lime-bordeaux, in the protection of potato foliage against diseases and insects, as it did in 1920. It should be remembered, however, that in experiment 2 of 1921, in which the sprayed plots outyielded the dusted plots by a significant margin, the spraying was done more thoroughly than in 1920, and the distribution of dust to the foliage from the crude power machines was not so thorough as that obtained with the hand duster in the preceding year. Although the sprayed plants in experiment 1 remained green as long as the dusted vines and sustained less injury from flea beetles and blight, yet the dusted plots produced an apparently significant increase in yield over the sprayed plots (table 16), due, no doubt, to the greater vine injury produced during the double applications of the spray. As can be seen from the data in table 16, the treated plots in both experiments produced marked increases in yield over the control plots.

In Washington County[17]

The experiments in Washington County were conducted in the fields of farmers who grow mainly American Giant potatoes. Only a small proportion of the growers had been spraying regularly for late blight, due chiefly to the inconveniences experienced in handling spray machines in a hilly country. As a result, in certain years heavy losses were sustained from insect injury and late blight.

[17] The experiments conducted in Washington County, although planned by and carried out under the general direction of the writer, were under the direct supervision of F. Dickson, at that time a graduate student in the Department of Plant Pathology at Cornell University, who personally supervised the spraying and did most of the dusting.

The dust mixture for the first application in each experiment was Sanders' copper-lime-arsenic dust, containing 5 per cent of copper and applied at the rate of 34 pounds per acre. In the second application, the same dust was applied at the rate of 60 pounds per acre. For the remaining applications, a dust containing 6 per cent of copper was applied at the rate of 50 pounds per acre. The spray for the first application was a 4–4–50 bordeaux mixture, and that for the remaining applications a 6–6–50 mixture, each applied at the rate of 100 gallons per acre. Hence, in all of the experiments, approximately equivalent amounts of copper were used in the two fungicides at each application.

For the control of the Colorado potato beetle in the check plots in all of the experiments, a dust mixture containing paris green and hydrated lime was used. The growers' own sprayers were employed in the experimental plots, and the formula of the bordeaux mixture was varied so as to equal in copper content that of the corresponding dust application.

Experiment 1 (Farm of F. McEachron, Salem, New York).—An experiment was conducted on the McEachron farm to compare the merits of several kinds of machines and to compare the copper-lime dust with the bordeaux mixture. The field was 21 rods in length, and was planted in checked rows. The following machines were used in the test: (1) A Eureka traction sprayer with eight nozzles, two to a row, and carrying a pressure of from 100 to 150 pounds; (2) a Niagara 1921-model engine-power potato duster, with eight nozzles, two to a row; (3) a Johnson traction potato duster with four nozzles, one to a row; (4) an Ideal Cotton duster, a one-wheel traction machine with two nozzles, one to a row; (5) a Leggett hand duster with one nozzle. The hand duster was operated up one side of the row and down the opposite side, to give a two-nozzle-to-a-row effect. All dust applications were made in the morning while the dew was on the vines, and spray applications were made later in the day when the vines were dry. Eight applications were made between June 20 and September 7.

The number of replications for each treatment was six. However, due to the fact that toward the end of the season the last two replications on one side of the experiment were washed out during a heavy rainstorm, only four of the plots for each treatment were dug. The arrangement of plots in the experiment is shown in table 17. At harvest time the two middle rows of the four-row plots were dug and weighed, and one row from the one-row and the two-row plots. In computing the yields under the different treatments, the last two plots shown in the table were not taken into account due to the fact that they also were partly washed out.

Unfortunately, since no early or late blight developed in the experiments, no comparison could be made as to the fungicidal value of the materials. The dust containing calcium arsenate controlled the Colorado potato beetle as effectively as did the paris green in the bordeaux mixture. Flea beetles and leaf hoppers were present in large numbers, and were decidedly more destructive on the untreated than on the protected vines. Also, tipburn was more severe on the checks, and was the cause of most of the injury which caused premature death of the vines in that plot. The sprayed plots showed the least amount of injury from these sources, and the plants dusted by hand showed only slightly more. Practically no difference could be detected in the degree of injury in the other treated plots. The vines that were dusted with the three horse-drawn machines

TABLE 17. YIELD OF AMERICAN GIANT POTATOES SPRAYED WITH BORDEAUX MIXTURE AND DUSTED WITH COPPER-LIME DUST, USING FOUR TYPES OF DUSTERS

(Farm of Foster McEachron, Salem, New York)

Machine used	Number of rows in plots	Number of rows dug	Yield, in bushels per acre			
			Series I	Series II	Series III	Series IV
Check	4	2	217.8	256.8	243.2	227.2
Ideal Cotton duster; 2-row, traction	2	1	235.2	272.8	249.6	245.6
Leggett hand duster	1	1	264.4	296.8	264.8	276.8
Eureka sprayer; 4-row, traction	4	2	268.0	278.0	252.8	266.0
Johnson duster; 4-row, traction	4	2	253.0	282.0	246.0	240.4*
Niagara duster; 4-row, engine power	4	2	261.2	280.0	251.2	214.0*

Average increase or decrease in yield:

Hand duster over check	= +38.65 ± 0.98
Niagara duster over check	= +20.08 ± 4.56
Sprayer over Niagara duster	= + 1.83 ± 4.90
Sprayer below hand duster	= − 9.45 ± 3.30
Ideal Cotton duster over check	= +14.55 ± 1.82
Hand duster over Ideal Cotton duster	= +25.00 ± 2.25
Johnson duster over check	= +16.47 ± 3.57
Sprayer over Johnson duster	= + 5.80 ± 5.30
Sprayer over Ideal Cotton duster	= +15.52 ± 4.37

* Due to the fact that these plots were partly washed away, the yields were not considered in calculating the averages.

remained green about two weeks longer than the vines in the check plots, and those protected with the sprayer and the hand duster remained green three or four days longer than those dusted with the horse-drawn machines.

Regarding the relative efficiency of the machines in distributing the material on the vines, the sprayed plants showed a thicker coating of material than did those that were dusted by hand, and both presented a uniform covering on the upper side of the foliage. The dust coating on the foliage of the other plots was neither so heavy nor so uniformly distributed. The vines dusted with the power machine carrying two nozzles to a row were more thoroughly covered than those dusted with the traction machines with one nozzle to a row.

In general the yields of the plots under the different treatments corresponded closely with the respective degrees of protection against tipburn, hopper burn, and flea beetles (table 17). The hand-dusted plot, however, produced an apparently significant increase in yield over the sprayed plots, even though the sprayed plots showed less injury from disease and insects. Undoubtedly there was an injurious effect caused by the machines and horses passing through the plots. Significant increases in yield over the untreated plots were obtained with each of the treatments, and that obtained by the use of the hand duster was higher than that for the sprayer and that for the best of the horse-drawn dusters. A marked

increase in yield was obtained with the hand duster over the Ideal Cotton duster, but there was no significant difference between the yields with the Niagara duster and with the sprayer.

Experiment 2 (Farm of Henry F. Reid, Belcher, New York).—On the Reid farm, Sanders' copper-lime dust, applied with a hand duster, was compared with bordeaux mixture applied with a four-row Iron Age traction machine, equipped with two nozzles to a row and carrying a pressure of from 150 to 200 pounds. The field was 50 rods in length. There were four sprayed plots containing four rows each, four dusted plots with three rows each, and two untreated plots with four rows each. The arrangement of the plots in the experiment is shown in table 18. At digging time

TABLE 18. YIELD OF AMERICAN GIANT POTATOES SPRAYED WITH BORDEAUX MIXTURE AND DUSTED WITH COPPER-LIME DUST, 1921

(Farm of Henry F. Reid, Belcher, New York)

Treatment	Number of rows in plots	Number of rows dug	Yield, in bushels per acre	
			Series I	Series II
Sprayed	4	2	255.2	323.7
Dusted	3	1	303.5	346.1
Sprayed	4	2	292.8	318.9
Dusted	3	1	299.2	285.5
Check	4	2	229.6	277.3

Average increase or decrease in yield:

Dust over check ..... = +45.80 ± 25.30
Spray below dust ..... = − 4.32 ± 9.80

the two middle rows of each four-row plot, and the middle row of each three-row plot, were dug and weighed. There were eight applications of fungicide between July 6 and September 13.

No fungous diseases developed in the plots. Tipburn was severe on the unprotected plots, and caused the greater part of the injury to the foliage. Practically no tipburn injury was observed on the treated vines. The Colorado potato beetles were effectively controlled in the first two applications by the calcium arsenate in the dust and by the paris green in the bordeaux mixture. Injury from flea beetles and leaf hoppers, while not severe on either the dusted or the sprayed plots, was more noticeable on the dusted foliage and was decidedly more severe on the control plots. The dusted and the sprayed vines remained green about two weeks longer than did the vines on the check plots. The dusted plots produced a marked increase in yield over the control plots (table 18), but, due to the smaller number of check plots in this experiment, the difference of 45.8 bushels between the average for the checks and that for the dusted plots did not prove significant. It was observed throughout the season that the sprayed vines sustained slightly less injury from tipburn and insects than did the dusted plants, but the latter yielded as much as the former. Here again it appears that the plots treated with the horse-drawn machine might have

suffered a handicap in the way of greater mechanical injury either to the roots or to the tops, or to both.

Experiment 3 (Farm of Nelson Pratt, Cossayuna, New York).—In the third experiment, plots dusted with a copper-lime dust were compared with untreated plots. The machinery included the Leggett hand duster, and a Johnson traction duster equipped with four nozzles, one to a row. The field was 15 rods in length and was planted in checked rows. The checks contained four rows each, the hand-dusted plots one row, and the plots dusted with the traction machine eight rows each. The first two applications included poison for the Colorado potato beetle. Seven applications of dust were made between July 1 and September 12. At harvest time each hand-dusted row, and the two middle rows in each of the other plots, were dug and weighed

No fungous diseases were present. Tipburn, however, was severe in the control plots and was practically absent in the dusted rows. Calcium arsenate in the copper-lime dust controlled the Colorado potato beetle practically as effectively as did the paris green in the checks. Toward the end of August, there developed a second but light infestation of these beetles. The beetles avoided the dusted vines almost entirely, and fed only on the unprotected plants. Flea beetles and leaf hoppers were numerous on the check plots, but produced only slight injury on the dusted plants. During the latter part of the season, a light infestation of aphids developed with equal severity in all of the plots.

The vines dusted by hand were more uniformly covered than were those in the plots dusted with the traction machine. Although very little difference could be noted in the degree of injury on the foliage dusted with the two machines, yet it is seen from the data in table 19 that the hand-

TABLE 19. YIELD OF AMERICAN GIANT POTATOES DUSTED WITH COPPER-LIME DUST, USING A TRACTION MACHINE AND A HAND DUSTER, 1921

(Farm of Nelson Pratt, Cossayuna, New York)

Duster used	Number of rows in plots	Number of rows dug	Yield, in bushels per acre					
			Series I	Series II	Series III	Series IV	Series V	Series VI
Traction duster, 4-row	8	2	255.5	307.2	312.0	264.5	248.5	248.5
Hand duster	1	1	317.8	321.3	268.8	309.3	290.1	275.2
Check	4	2	293.9	286.9	266.1	284.8	205.3	272.0

Average increase in yield:

Hand duster over check ..... = 27.71 ± 7.73
Hand duster over traction machine ..... = 24.50 ± 9.43

dusted plots produced a significant increase in yield over the checks, while the plots dusted with the horse-drawn machine did not. This difference in yield obtained under the two treatments can probably be attributed to the same factor mentioned in connection with experiments 1 and 2 — that is, to the greater mechanical injury produced by the horses and the wheels.

Experiment 4 (Farm of William Morgan, West Hebron, New York).—A field of American Giant potatoes was under experiment on the Morgan farm. The field was 32 rods in length. The arrangement of the plots is shown in table 20. The copper-lime dust was applied with a hand duster, and the bordeaux mixture was applied with a Eureka traction sprayer

TABLE 20. YIELD OF AMERICAN GIANT POTATOES SPRAYED WITH BORDEAUX MIXTURE AND DUSTED WITH COPPER-LIME DUST, 1921

(Farm of William Morgan, West Hebron, New York)

Treatment	Number of rows in plots	Number of rows dug	Yield, in bushels per acre			
			Series I	Series II	Series III	Series IV
Sprayed	4	2	139.5	144.7	138.1	141.4
Dusted	3	1	168.5	157.3	160.1	163.3
Check	4	2	165.7	161.9	154.9	158.7

Average increase or decrease in yield:

Dust over check	= + 2.50 ± 0.80
Spray below check	= −18.15 ± 1.56
Spray below dust	= −21.54 ± 2.06

carrying eight nozzles, two to a row. Eight applications of both fungicides were made between July 5 and September 14. In determining the yields, the middle rows of the plots were dug and weighed.

Fungous diseases were absent. Leaf hoppers and flea beetles were injurious on the checks, but not so destructive as the tipburn resulting from the hot, dry weather. Injury from these sources was decidedly less severe on the treated vines, the sprayed foliage escaping with slightly less injury than the dusted vines. The plants in the checks died from ten days to two weeks earlier than the plants in the protected plots. Practically no difference was noted between the length of the growing period of the dusted and the sprayed plants.

It will be noted from the data in table 20, that, contrary to the results obtained in the three preceding experiments, the sprayed plots yielded less by a marked difference than did the control plots. Although the dusted plots yielded, on the average, only 2.5 bushels more than did the check plots, the difference appears to be significant. The dusted plants also produced a considerable increase in yield, 21.54 bushels, over the sprayed plots.

This section of the county was particularly hot and dry, and consequently the conditions for growth were unfavorable. The yield for the entire field was low. Judging from the results of experiments 1, 2, and 3, in which there occurred an apparent reduction in yield where horse-drawn dusters or sprayers were employed, the results of experiment 4 are not surprising because the injury that was inflicted on the plants by the spraying was not overcome by the beneficial effects of the materials, due to the unfavorable growing season. Since the degree of this mechanical injury was by no means so great in the plots dusted by hand, or in the check

plots which received two applications of paris-green dust applied with the hand duster, there resulted a proportionately higher beneficia effect from the dusting than from the spraying.

Experiment 5 (Farm of J. Crowley, Hudson Falls, New York).—The fifth experiment was conducted in a field of Peerless potatoes, which was located in the low muck lands of a region known as Dunham's Basin. Six e ght-row dusted plots alternated with four-row check plots. The field was 30 rods in length, and was planted in checked rows. Six applications of dust were made between July 9 and August 30. The duster used on this farm was a four-row Johnson traction machine with one nozzle to a row. At harvest time the two middle rows of the check plots, and the four middle rows of the dusted plots, were dug and weighed (table 21).

TABLE 21. YIELD OF PEERLESS POTATOES DUSTED WITH COPPER-LIME DUST, 1921
(Farm of J. Crowley, Hudson Falls, New York)

Treatment	Number of rows in plots	Number of rows dug	Yield, in bushels per acre						
			Series I	Series II	Series III	Series IV	Series V	Series VI	Series VII
Dusted...	8	4	115.2	129.7	133.7	132.3	127.3	135.0	.....
Check....	4	2	128.2	131.7	147.0	140.4	165.4*	153.0	140.1

Average increase in yield of checks over dusted plots = 13.26 ± 1.35 bushels

* Due to the fact that this plot lay in a dead furrow and yielded abnormally high, the yields of the two nearest dusted plots were compared with the other adjacent controls.

The entire field, including the area under experiment, was a level bed of black muck. During the early part of the season, the plants made a vigorous growth. The weather, however, turned hot and dry, and remained so during most of the time until September. Injury to the tops from tipburn, flea beetles, and leaf hoppers was only slight, even in the check plots. During the drought in August, the muck became intensely hot, and the lower leaves of the plants began to turn yellow and die. During the last week of that month the entire field, the dusted and the check plants alike, died more or less suddenly as if they had been killed by the hot, dry soil. The foliage did not exhibit the typical symptoms of tipburn or hopper-burn. The yield over the entire field was low, due to the premature death of the vines. Furthermore, there was a significant decrease in yield of the dusted plants below the control plants, due apparently to mechanical injury from driving through the plots with the duster. Had there been hand-dusted plots in the experiment, in all probability they would probably have yielded about the same as did the control plots.

Summary of results in Washington County, 1921.—In comparing Sanders' copper-lime dust with bordeaux spray for the control of foliage injury caused by tipburn, flea beetles, and leaf hoppers, the bordeaux mixture proved slightly superior to the dust, even when the dust was applied evenly to the foliage with a hand duster. Both the spray and the dust

furnished a high degree of control. On the other hand, by comparing the yields of plots dusted with the hand duster and those sprayed with a traction sprayer, the dusted vines yielded as much as, or more than, the sprayed plants. Also, the hand-dusted plots, as a rule, yielded higher than did the plots dusted with traction or power machines. In experiment 5, in which only a traction duster was used and in which the entire field died prematurely, due apparently to the abnormally high soil temperature which killed the treated and the untreated plants alike, the check plots yielded more tubers, by a significant figure, than did the dusted rows. In general, the results on comparative yields indicate strongly that there was a certain amount of injury inflicted to the plants by the horses and the machines. This sort of injury would probably be only slight in a hand-dusted plot. The nature of the growing season, in all probability, determines whether or not this injurious effect will be overcome through the protective action of the fungicide on the foliage. If the season is favorable for normal growth, the deleterious effect will be overshadowed by the increase in yield due to the protection against diseases and insects. If the season is unfavorable for growth, the injurious effect may remain greater than any beneficial effect derived from protection.

Experiments of 1922

The experiments of 1922 for the comparison of copper-lime dust with bordeaux mixture, were located on the same farms in Suffolk County as those for 1921. The test was conducted in duplicate on Green Mountain potatoes, and there were six dusted, six sprayed, and three check plots. Each field was 24 rods long. All of the plots contained four rows each, with the exception of the sprayed plots in experiment 2, which contained six rows. The dusts were mixed on the farm, in a mixer operated by gas-engine power.

For beetle control, calcium arsenate was added to the dust mixture for the first two applications in each experiment. Lead-arsenate was included in the corresponding spray applications. Thirteen applications were made in experiment 1 between June 10 and August 19, and fourteen in experiment 2 between June 12 and August 16. The dust applications were made in the morning while the dew was on the foliage, and the spray applications were made later in the same day on the dry vines.

The copper-lime dusts used during the season contained, respectively, 8.5 per cent and 10 per cent of copper. In experiment 1, located on the farm of C. E. Dimon, Southampton, New York, the dust containing 10 per cent of copper was employed in the first to the seventh applications, and in the twelfth and thirteenth. The 8.5-per-cent-copper mixture was used in the other applications. In experiment 2, located on the farm of H. T. Fahy, Bridgehampton, New York, the mixture with 10 per cent of copper was applied in the first to the eighth applications and in the thirteenth and fourteenth, and the 8.5-per-cent dust in the remaining ones. It was the intention to apply about 3 pounds of copper per acre at each application. The average for all of the applications was 3.73 pounds in experiment 1, and 4.26 pounds in experiment 2, at each application. The spray mixture was the same in both experiments—a 6–4–50 preparation, or a formula with that ratio of copper sulfate to lime—but it varied upward

or downward in copper content to equal that of the dust application of the same day. The rate of application was 100 gallons per acre, and the average quantity of copper applied per acre at each application throughout the season was 3.88 pounds for experiment 1 and 3.5 pounds for experiment 2.

The duster was driven through the control plots each time that the adjacent dusted and sprayed plots received an application. By observing this practice as long as there was foliage on the checks, any injury to the plants from the wheels or the horses would be equalized in all plots. At digging time, the two middle rows of each plot were dug and the rows were divided into two portions of equal lengths. The tubers in each end were then collected separately and weighed.

The dusting and spraying machinery used in 1922 was superior to that used in the preceding year. In experiment 1, during the first half of the season a Brown sprayer with two double-action cylinders was employed. A 30-gallon air-pressure reserve tank made it possible to maintain maximum pressure while the sprayer was being turned at the end of the plots. The boom was altered so that four-row plots could be sprayed, with two nozzles to a row. The nozzles of each pair were placed about 20 inches apart and were directed slightly inward as well as downward. The average pressure for the six applications made with this machine was 195 pounds, the lowest being 160 and the highest 225 pounds. No such variation in pressure, however, occurred in one day. For the remainder of the season, a 1922-model Yellow Jacket sprayer was employed. The boom of this machine, also, was altered for spraying four-row plots, with two nozzles to a row. Although the reserve air tank on the Yellow Jacket was smaller, this machine proved, on the whole, much more reliable in applying the spray at a uniformly high pressure. An average of 225 pounds was maintained during the remaining seven applications, the lowest pressure being 220 pounds and the highest 270 pounds.

The spraying machines for experiment 2 were not so efficient as those used in experiment 1. The first two applications were made with an Iron Age sprayer that had been operated previously through one or two seasons. It carried twelve nozzles, two to a row, and maintained a pressure of only about 145 pounds. During the remainder of the season, a new Red Jacket machine was available. This machine was fitted with a boom for spraying six rows, with two nozzles to a row. A uniform pressure of from 200 to 210 pounds was maintained.

The duster used in experiment 1 was the 1922-model Niagara F–22–P power potato duster equipped with a 5-horse-power Pierson engine. This duster proved to be in many respects a decided improvement over the 1921-model machine, particularly in the increase in size and speed of the fan, with a resulting increase in air pressure. The distributing system, with larger nozzles and a greater diameter of pipes, also was found to be more efficient than the type on the duster of the preceding year. Due to the fact that the hopper and the fan case were constructed of aluminum, and the main axle turned in long roller-bearings, the weight and the draft were decreased considerably.

Although the machine represented one of the best on the market available for potato dusting, yet there were several faulty features that could not then be entirely remedied. One of these was the failure of the nozzles

to spread the dust out sufficiently to envelop the plants completely and give an even distribution of material to the individual row, in spite of the fact that a blast of air sufficiently strong to blow the dust out forcibly could be created. Another fault was the uneven flow of air and dust from the main pipe into the four large distributing pipes. The result was an uneven delivery of dust to the different rows, in fact a uniform decrease from one outer pair of nozzles to the opposite outer pair. The third fault consisted in an occasional side delivery of dust and wind from one or more of the nozzles, resulting in an uneven application or a streaking effect on the row. The first and third sources of trouble were to a large extent corrected at the ouset of the experiment, but the cause of the second fault was not ascertained until the dusting season was half over. Until that time, the machine was driven through the plots in opposite directions during successive applications, in order to equalize as far as possible the amount of dust applied to the different rows. To overcome the effect of strong winds, an apron was constructed and so attached to the boom that it hung over and behind the nozzles. This apron also protected the nozzles from side winds.

In experiment 2 the same machine that was operated during the preceding season, the 1921-model Niagara power potato duster, was employed again in 1922. The distributing pipes and nozzles, however, were replaced by those for the 1922 model. While fairly uniform amounts of dust were delivered from the four pairs of nozzles, the same difficulties as to the manner of dust delivery from the individual outlets were experienced with this duster as were mentioned in connection with the 1922 machine. Furthermore, owing to the fact that the speed of the engine was difficult to regulate at times, during several applications the amount of dust fed from the hopper was so light that it was necessary to drive through the plots twice in order to apply sufficient fungicide.

Both early blight and late blight were present in 1922. In both experiments, late-blight infection was severe in the check plots and caused the greater part of the premature death of the foliage. While it was present in the treated rows as a light infection, it occasioned only a very small loss of foliage, and was no more evident in the dusted plots than in the sprayed plots. As a whole, the degree of infection was slightly heavier in experiment 2 than in experiment 1. Early blight did not become serious in either experiment, but it was more difficult to control than late blight. A more or less uniform infection was present in both the dusted and the sprayed rows during the greater part of the season. The injury to the untreated plants, however, was greater than that suffered by the treated plants.

Injury from flea beetles was slightly heavier in the dusted plots, in both experiments, than in the sprayed plots. In either case the degree of injury was very slight as compared with that on the unprotected vines. Tipburn was not an important factor that season, but was more noticeable on the check plants than on the dusted or the sprayed foliage. Aphids, while represented by a fairly heavy infestation of about a week's duration, occasioned no serious damage, and were more or less equally distributed in the treated and the check plots. No leaf hoppers were observed.

During practically the entire season the sprayed plants appeared to have a heavier coating of copper on the leaves, especially on their upper

side, than did the dusted vines. The dusted plants, on the other hand, showed more copper on such parts as stalks, branches, and the under side of leaflets, than did those sprayed with bordeaux mixture. This feature was particularly noticeable in the experiments on the relative adhesiveness of the dust and the spray mixtures, in which observations and tests for copper were made on plots dusted carefully with a good hand machine.

The difference in the rate of vine growth in the protected and the unprotected plots was more marked in 1922 than in 1921. There was no apparent difference in the size and the appearance of the dusted and the sprayed vines; the check plants, however, in both experiments grew for a time more rapidly than did the treated vines, resulting in a greater height and a greater spread of tops. This difference was first noticed between the third and the fourth application, and it continued to increase for at least three weeks, or until the foliage of the checks began to show excessive injury from flea beetles, late blight, and tipburn. After a greater part of the leaves had been stripped from the check vines, the stalks towered above the plants in the adjacent plots that had received copper. The copper-lime dust containing 10 per cent of copper, which was used during the first part of the season, appeared to produce a slight burning of the foliage, but the injury was not considered severe enough to account for any dwarfing effect in the growth of the plant as a whole. Furthermore, the sprayed vines on which no copper injury was apparent exhibited the same stunted effect. Since the check plots received a corresponding amount of injury from horses and wheels to that received by the dusted and the sprayed plots, it seems probable that the apparent injurious effect may have been due to the presence of the copper coatings.

In experiment 1, the dusted vines were as green and as healthy in appearance, and remained green as long, as those in the sprayed plots. The foliage of the checks was dead by August 2, while that of the treated plots did not die until August 28. In experiment 2, the dusted vines, during the latter half of the spraying season, showed the effect of the mechanical injury inflicted on them by the double applications of the fungicide. In six applications, the duster was driven through the plots twice. The sprayed plants lived a few days longer than did the dusted plants, but the dusted plants remained green three weeks longer than did the check plants.

Concerning the yields of the plots under different treatments, in experiment 1, in which the dusted and the sprayed plants exhibited more or less equal degrees of protection against diseases and insects, and in which the amount of injury due to horses and to machines was the same under the two treatments, the yields were approximately the same (table 22). The average difference, while only a little less than four bushels per acre, might be considered a significant decrease for the spray below the dust. In experiment 2, in which conditions were practically identical with those in the first experiment aside from the double applications of dust that were made on six different occasions, the sprayed plots produced a significant increase in yield over the dusted plots. In both experiments, notable increases in yield were obtained in the treated plots over the control plots.

Summary of results for 1922.— The results for 1922 in Suffolk County indicate that, during a season when early blight, late blight, and flea beetles were important factors in the experiments, copper-lime dust applied

TABLE 22. YIELD OF GREEN MOUNTAIN POTATOES DUSTED WITH COPPER-LIME DUST AND SPRAYED WITH BORDEAUX MIXTURE, 1922

(Farms of C. E. Dimon, Southampton, New York, and H. T. Fahy, Bridgehampton, New York)

Treatment	Yield, in bushels per acre			
	Experiment 1		Experiment 2	
	North end	South end	North end	South end
Dusted	378.8	384.7	263.9	278.7
Sprayed	372.0	378.7	334.5	319.8
Check	305.4	314.7	236.4	230.1
Dusted	374.7	396.0	288.0	288.8
Sprayed	383.3	397.4	317.1	318.2
Dusted	410.4	397.3	305.4	313.5
Sprayed	412.8	420.1	327.8	341.9
Check	314.8	335.3	263.1	246.5
Dusted	411.2	422.7	298.8	310.8
Sprayed	400.4	414.0	326.9	320.2
Dusted	403.9	394.0	280.0	283.6
Sprayed	385.0	371.9	323.7	326.8
Check	290.0	298.7	233.2	212.2
Dusted	387.3	395.4	285.8	258.9
Sprayed	387.9	395.3	327.1	319.7

Experiment 1: Average increase or decrease in yield:

Spray below dust ..... = − 3.98 ± 1.38
Dust over check ..... = +87.07 ± 3.56

Experiment 2: Average increase in yield:

Spray over dust ..... = +36.97 ± 3.35
Dust over check ..... = +51.26 ± 2.64

at rates sufficiently high to give a prominent coating on the upper sides of the leaves controlled the fungous diseases as effectively as did bordeaux mixture applied at an equal rate with an exceptionally good sprayer. The bordeaux coating proved slightly superior in controlling flea beetles and tipburn. Further evidence was obtained that excessive driving through plots with a horse-drawn duster or sprayer results in additional injury to the plants, accompanied by a decrease in yield. The better duster in use in 1922 did not compare in efficiency with well-equipped traction sprayers.

Summary of results for 1920, 1921, and 1922

The results of the three years of experimentation in comparing copper-lime dust with bordeaux mixture for the control of fungous diseases and insect pests, indicate that copper-lime dusts containing 6, 8.5, and 10 per cent of copper, when applied to damp foliage, with distribution as thorough as that furnished by a good hand duster or the best of the power dusters, controlled early and late blight and aphids as effectively as did lime-bordeaux of equal copper content, and more effectively than did soda-bordeaux. In the control of flea beetles and tipburn the dusts were more effective than soda-bordeaux but slightly less effective than lime-bordeaux.

The lime-bordeaux was more effective also against the leaf hopper. Other conditions being equal, the yields were proportional to the degree of protection against fungous diseases, tipburn, and flea beetles, which were the major sources of injury. Hand-dusted plots, in general, yielded higher than did the plots that were dusted or sprayed with horse-drawn machines, due apparently to the lesser amount of injury to the plants in the rows dusted by hand. Under conditions calling for double applications of either the dust or the spray during a part or all of the season, a decided reduction in yield resulted in those plots through which the machine was driven an extra number of times, due apparently to the additional mechanical injury.

A summary of the results for the three years (table 23) shows that the sprayed plots produced, on the average, a gain over the dusted plots of

TABLE 23. SUMMARY OF DATA SHOWING DIFFERENCES IN YIELD OF POTATOES SPRAYED WITH BORDEAUX MIXTURE AND DUSTED WITH COPPER-LIME DUST, 1920, 1921, AND 1922

Year	Major sources of injury	Data from table no.	Plot no.	Increase or decrease in yield (bushels per acre), spray over or below dust	
				Individual*	Average
1920	Late blight; flea beetles	14	1	−10.50	−10.50
		15	1	−25.00	−25.00
1921	Late blight; flea beetles; tipburn	16 Experiment 1	1	−29.70	
			2	−18.40	
			3	+ 1.00	
			4	− 3.90	
			5	+ 5.80	
			6	−20.50	−10.95 ± 3.84
1921	Late blight; flea beetles	16 Experiment 2	1	+45.00	
			2	+23.90	
			3	+24.70	
			4	+20.60	
			5	+54.50	
			6	+25.10	+32.30 ± 3.84
1921	Flea beetles; tipburn	17 Ideal Cotton duster	1	+32.80	
			2	+ 3.20	
			3	+ 8.50	
			4	+17.60	+15.52 ± 4.37
		17 Hand duster	1	+ 3.60	
			2	−20.10	
			3	− 8.80	
			4	−12.50	− 9.45 ± 3.30
		17 Johnson duster	1	+17.10	
			2	− 9.30	
			3	+ 9.60	+ 5.80 ± 5.30

TABLE 23 (*concluded*)

Year	Major sources of injury	Data from table no.	Plot no.	Increase or decrease in yield (bushels per acre), spray over or below dust	
				Individual*	Average
1921	Flea beetles; tipburn	17 Niagara duster	1	+11.00	
			2	−12.60	
			3	+ 7.10	+ 1.83 ± 4.90
		18	1	−29.50	
			2	+ 3.50	
			3	−24.90	
			4	+33.60	− 4.32 ± 9.80
		20	1	−29.00	
			2	−14.34	
			3	−19.81	
			4	−23.00	−21.54 ± 2.06
1922	Late blight; flea beetles	22 Experiment 1	1	− 6.80	
			2	+ 4.80	
			3	−12.40	
			4	− 6.70	
			5	−11.20	
			6	− 0.30	
			7	− 6.00	
			8	− 4.80	
			9	+11.40	
			10	− 6.70	
			11	− 1.10	
			12	− 7.90	− 3.98 ± 1.38
		22 Experiment 2	1	+70.60	
			2	+34.90	
			3	+17.05	
			4	+28.39	
			5	+45.30	
			6	+40.16	
			7	+41.10	
			8	+29.93	
			9	+16.55	
			10	+16.63	
			11	+39.90	
			12	+63.16	+36.97 ± 3.35
	Average				+7.205 ± 2.11

* For method of calculation used for this column, see footnote 16, page 33.

7.205 ± 2.11 bushels per acre. This difference may be considered significant, and in all probability represents, under the conditions of the experiments, the difference between the relative values of the two methods of protection.

COMPARISON OF EFFECTIVENESS OF COPPER-LIME DUST APPLIED TO WET AND TO DRY FOLIAGE

In 1922 an experiment was conducted on Green Mountain potatoes to compare the effectiveness of dusting wet and dry foliage for the control of diseases and insects. The test was located on the farm of C. E. Dimon, Southampton, New York. All of the plots were 22 rods in length and four rows in width, and were arranged in the experiment in the order shown in table 24. Thirteen applications of dust were made at intervals of from five to seven days. A dust containing 10 per cent of copper was used for

TABLE 24. YIELD OF GREEN MOUNTAIN POTATOES DUSTED WITH COPPER-LIME DUST WHEN THE FOLIAGE WAS WET AND WHEN IT WAS DRY, 1922

(Farm of C. E. Dimon, Southampton, New York)

Condition of vines when dusted	Yield, in bushels per acre	
	North end of plot	South end of plot
Wet	388.8	406.4
Dry	404.0	408.0
Wet	388.4	392.8
Dry	373.2	383.2
Wet (hand duster)	371.2	372.0
Wet	384.8	388.4
Dry	386.0	388.8
Check	320.0	315.2
Wet	460.8	397.2
Dry	402.8	401.2
Wet	366.4	350.0
Dry	376.4	381.4
Wet	365.2	352.4
Dry	384.4	380.0

Average increase in yield:

Plants dusted when dry over those dusted when wet..... = 9.91 ± 2.80
Plants dusted when wet, power machine over hand duster.. = 16.33 ± 1.03
Plants dusted when wet over check plants..... = 76.43 ± 2.00

nine of the applications, and one containing 8½ per cent of copper for the other four applications. The plot dusted by hand and those dusted when wet received applications in the early morning, and those dusted when the vines were dry received applications later in the same day, usually in the early part of the afternoon. Even in the middle of the afternoon on some days the lower leaves were not entirely dry. A 1922 Niagara power potato duster and a Feeny hand duster were used. In each application, approximately equal amounts of dust were applied by the power machine to the wet and to the dry foliage. The average amount of copper applied per acre in each application was 3.8 pounds for the power machine and 3.52 pounds for the hand machine. An apron attached to the boom was used whenever a strong wind was blowing. On days when applications were made, the duster was driven through the check plot and through the plot dusted by hand in order to equalize any injury that might occur

from the horses and from the wheels of the machine. At harvest time, the plots were divided into two equal parts and the tubers for each plot were gathered and weighed.

In the discussion on the relative adhesiveness of fungicides, it was pointed out that under both laboratory and field conditions, more copper-lime dust was retained by wet than by dry foliage, and that proportionately less dust was washed from the vines between applications. The field experiment referred to under that topic (page 16) is the one under consideration here.

The foliage that was dusted when dry exhibited at all times a very light coating of copper. After dashing rains, little, if any, of the characteristic blue color of the bordeaux coating could be distinguished on the foliage when this was observed even at close range. The lowermost leaves showed the heaviest layer of "copper" coating, these being the ones that were sometimes damp when the applications were made. In the plots that were dusted when the foliage was wet, on the other hand, there was always present a relatively heavy, prominent copper coating. The plants of the hand-dusted plot were more evenly covered than those that were dusted with the power machine. During each application, each of the four rows of the plot dusted by hand was dusted up one side and down the opposite side, so that a two-nozzle-to-the-row effect could be obtained.

Late blight was at no time serious in any of the treated plots, but it was considerably more in evidence in the plots that were dusted when dry than in the other dusted rows. Although the plants in the control plot suffered severely from this disease during the latter part of the season, the infection in the plots dusted when dry, which gave light tests for copper, was relatively low, showing that a very light coating of the dust, if it was distributed reasonably well, was almost as effective as the heavier coating on the leaves that were dusted when wet. Early blight, and injury from tipburn and flea beetles, were decidedly more prominent in the check plot than in the plots that were dusted when the vines were wet, but only slightly more evident than in the plots that were dusted when dry. Evidently the difference in the thickness of the coating was influential in the control of the beetles and of tipburn, and the difference in the amount of copper was influential in the control of the fungous diseases. Injury from aphids was about equal in all of the plots.

Vine behavior, in the plots that were dusted when wet, was about the same with both the power duster and the hand machine. The check plot stood well above the rows that were dusted when wet, in size and spread of plants. Observations in this respect corresponded with those for the two preceding experiments (page 44). The plants in the plots that were dusted when dry, on the other hand, showed little if any dwarfing as compared with the check plot. The plots that were dusted when wet were dead on August 28, those that were dusted when dry on August 22, and the check plot on August 10.

It is interesting to note, concerning the relative yields (table 24), that even though the plants with the light coating of dust exhibited greater injury from early and late blight and from tipburn and flea beetles, and died from these causes nearly a week earlier, than the vines that were dusted when wet, yet they outyielded the latter by a significant margin. Apparently the additonal loss due to diseases and to insects, in excess of the loss

in the plots that were protected with the heavier coating of dust, was more than overcome by the additional vine growth and tuber development in the plots that were dusted when dry. It is difficult to explain the significant increase in yield of the plots that were dusted with the power machine when wet, over the plot that was dusted by hand when wet, unless it may be attributed to the additional injury to the plants caused by the operator walking through the vines in carrying the hand machine. It will be recalled that the power duster was driven through both the check plot and the hand-dusted plot. Since there was only one hand-dusted plot, and the degree of protection was as high in that plot as in the plots that were dusted with the power machine when wet, probably too much importance should not be attached to the increase in this particular case.

EFFICIENCY OF COPPER-LIME DUSTS CONTAINING DIFFERENT PERCENTAGES OF COPPER

Concerning the percentage of copper that should be used in copper-lime dust, Sanders and Kelsall (1920) state that they failed to obtain perfect control of late blight unless copper was present to the extent of 5 per cent or more, and that a mixture containing 7.5 per cent of copper gave better protection aga nst late blight and tuber rot than one containing 5 per cent of copper.

In 1921, three field experiments were conducted for the purpose of comparing the fungicidal values of dusts containing, respectively, 6, 8, and 10 per cent of copper. The 6-per-cent dust was compared with a 10-per-cent mixture, both at Southampton and at Bridgehampton, and with an 8-per-cent dust at Bridgehampton. In each experiment, equivalent amounts of copper were applied per acre in the two dusts under comparison. All applications were made in the morning, on wet foliage. A Niagara power potato duster was used on each farm. The tubers in the two middle rows of each plot were dug and weighed

Late blight, flea beetles, and tipburn were severe in the control plots of all three experiments. In experiment 1 at Southampton and experiment 2 at Bridgehampton, both the 6-per-cent and the 10-per-cent copper dust gave nearly perfect control of late blight and produced a marked reduction in injury from flea beetles and from tipburn. In experiment 3 at Bridgehampton, the plots that were dusted with the mixtures containing 6 and 8 per cent of copper showed considerable blight, and yielded at digging t me about $2\frac{1}{2}$ per cent of rotted tubers. The duster in this experiment did not distribute the material as effectively as did those on the other two farms. No appreciable differences were observed in the degree of protection of the two dusts in any of the experiments, or in the appearance of the copper coatings on the foliage and their relative adhesiveness. No copper injury was noticed on the foliage in any of the plots.

Regarding the yields, it is seen from the data in table 25 that there was no appreciable difference in the results obtained with the 6-per-cen and the 10-per-cent copper dust. In experiment 3, however (table 26), there were some indications that the 8-per-cent copper dust was superior to the 6-per-cent mixture, although the increase in yield is less than three times its probable error. Considering the results from the three experiments, there s ems to be little difference between the efficiency of the 6-per-cent copper dust and a dust contain ng 8 or 10 per cent of copper.

TABLE 25. YIELD OF GREEN MOUNTAIN POTATOES DUSTED WITH COPPER-LIME DUSTS CONTAINING, RESPECTIVELY, 6 AND 10 PER CENT OF COPPER

Per cent of copper in dust	Yield, in bushels per acre	
	Experiment 1*	Experiment 2†
6	252.0	.....
10	266.0	.....
6	259.2	231.5
10	253.8	225.0
6	261.0	194.5
10	268.2	207.0
Check	248.4	170.5
6	270.0	190.1
10	273.6	194.3
6	244.8	205.8
10	259.2	209.6
6	306.0	.....
10	280.8	.....

Average increase in yield for 10-per-cent dust over 6-per-cent dust:
Experiment 1 = 1.16 ± 5.80
Experiment 2 = 1.45 ± 2.62

* The plots were 26 rods long and 4 rows wide.
† The plots were 48 rods long and 4 rows wide.

TABLE 26. YIELD OF GREEN MOUNTAIN POTATOES DUSTED WITH COPPER-LIME DUSTS CONTAINING, RESPECTIVELY, 6 AND 8 PER CENT OF COPPER*

Per cent of copper in dust	Yield, in bushels per acre
6	274.3
8	314.5
6	314.5
Check	285.2
8	325.0
6	292.0
8	304.5
6	269.7
Check	233.3
8	250.0
6	275.0
8	274.5

Average increase in yield for 8-per-cent dust over 6-per-cent dust = 14.18 ± 6.3

* The plots were 32 rods long and 4 rows wide.

COMPARISON OF COPPER-LIME DUST WITH SULFUR DUST

The results of earlier investigations indicated that sulfur applied to potato foliage in a spray was beneficial in one case and harmful in another, in its effects on the foliage and the yield. Jones and Giddings (1909) reported the results of a comparison of lime-sulfur with bordeaux mixture

on potato foliage in 1908. Very little early blight and no late blight were present, but tipburn was an important factor. Two applications of bordeaux mixture gave better protection against tipburn than did four applications of lime-sulfur, and produced a gain in yield of 67 per cent over the check in comparison with a gain of 37 per cent for the lime-sulfur. Four applications of bordeaux mixture afforded more than twice the protection against tipburn as did the same number of applications of lime-sulfur, and gave an increase in yield of 141 per cent over the check.

Stewart and French (1912) reported that lime-sulfur 1–40 caused a dwarfing of potato plants and a reduction in yield of 39.5 bushels per acre below the checks, as compared with an increase in yield of 100.3 bushels per acre for bordeaux mixture 6–6–50. No foliage injury was observed from the use of the sulfur spray, and the only injury noticeable in the experiment was tipburn. The plots sprayed with bordeaux mixture outlived by a considerable margin those sprayed with lime-sulfur.

In 1921 two experiments were conducted for the purpose of comparing a copper-lime dust containing 6 per cent of copper, with dusting sulfur. Experiment 1 was located on the farm of C. E. Dimon, Southampton, New York, and experiment 2 on the farm of H. T. Fahy Bridgehampton, New York. The copper-lime dust was applied at the rate of 50 pounds per acre at each application, and the sulfur at the rate of about 40 to 45 pounds. All applications were made in the morning, on damp vines. The duster in each experiment was a Niagara power potato duster with eight nozzles, two to a row. The rows in experiment 1 were 26 rods in length, and those in experiment 2 were 38 rods Ten applications were made in experiment 1 and nine in experiment 2.

Late blight was present in both experiments, but was much more severe in experiment 1. While the copper-lime dust was much more effective than the sulfur in controlling the late-blight fungus, the sulfured plots did not show as much foliage blight as did the check plots, indicating that the sulfur possessed some fungicidal value. In both experiments the plants under the two treatments were the same in size and appearance until blight, flea beetles, and tipburn became apparent. During the latter half of the season the sulfured rows suffered nearly as heavily from those injuries as did the check rows, and they died about twelve to fourteen days earlier than did the vines that were dusted with copper-lime. In experiment 2, in which late blight and flea beetles were not so prevalent but in which tipburn was decidedly more severe, the plots dusted with copper-lime remained green only about a week longer than did the sulfured plots and ten days longer than did the check. No tuber rot developed in any of the plots. The plants on either side of the area used in experiment 2, which the grower sprayed with bordeaux mixture, lived for at least a week after the dusted vines in the experimental plots were dead.

No foliage injury was observed as a result of the use of either of the fungicides, nor was any stunting effect noticed.

In regard to the yields, it is seen from the data in table 27 that in experiment 1 the plots dusted with copper-lime produced a significant increase in yield over the sulfured plots, but in experiment 2 the increase in yield was not so marked.

Another experiment was conducted during the same year, involving the use of sulfur and of a mixture of sulfur and hydrated lime. One

TABLE 27. YIELD OF GREEN MOUNTAIN POTATOES DUSTED WITH COPPER-LIME DUST AND WITH SULFUR, 1921

(Farms of C. E. Dimon, Southampton, New York, and H. T. Fahy, Bridgehampton, New York)

Dust	Yield, in bushels per acre	
	Experiment 1	Experiment 2
Sulfur	141.5	115.0
Copper-lime	150.5	155.0
Sulfur	125.8	142.5
Copper-lime	155.3	146.0
Check	114.8	115.0
Sulfur	122.9	140.0
Copper-lime	144.7	147.0
Sulfur	134.9	153.0
Copper-lime	158.3	161.0
Check	132.6	.....
Sulfur	126.1	.....
Copper-lime	159.9	.....
Sulfur	139.7	.....
Copper-lime	153.1	.....

Average increase in yield of copper-lime dust over sulfur:
Experiment 1 = 21.34 ± 2.42
Experiment 2 = 13.91 ± 5.95

check plot of four rows was included. Late blight developed early in the plots and spread rapidly, and this disease, together with severe injury from flea beetles and from tipburn later in the season, caused the check p ants and the sulfured plants to die even earlier than did those in experiment 1 described above. The two experiments lay side by side. There was no appreciable difference in yield between the two treatments.

COPPER-LIME DUST COMPARED WITH NICOTINE DUSTS FOR APHIS CONTROL

In view of the fact that in some years aphids become destructive in Long Island potato fields, experiments were conducted to test the effectiveness of two nicotine dusts in comparison with a copper-lime dust containing no nicotine. One nicotine copper-lime dust, furnished by the Niagara Sprayer Company, contained about 6.5 per cent of metallic copper in the form of monohydrated copper sulfate, 10 per cent of calcium arsenate, and 1.9 per cent of nicotine sulfate; the remainder consisted of hydrated lime. The other nicotine dust, known as "Contact Special," was a mixture of dusting sulfur and finely ground tobacco shoots, with a nicotine content of about 1.9 per cent. The copper-lime dust used as a control fungicide was mixed to contain the same amount of copper and of calcium arsenate as the Niagara contact mixture. In each experiment a Niagara power potato duster was used. All applications were made in the early morning.

Experiment 1, 1921 (Farm of C. E. Dimon, Southampton, New York).—The first experiment comprised four plots dusted with the copper-lime

dust without nicotine, alternating with four plots treated with the copper-lime-nicotine mixture. The field was 26 rods in length. Each material was applied at the rate of about 50 pounds per acre. Two applications of a copper-lime dust were made by the grower before the infestation appeared and the experiment began, and three were made after the termination of the test. The period of infestation lasted about five weeks, but was serious for only two or three weeks. Six applications of dusts were made in the experiment.

The two dusts were equally effective in controlling late blight, flea beetles, and tipburn. Observations indicated that there was a marked degree of aphis control in the nicotine plots. During the period of heaviest infestation, there were more green uninjured leaves and fewer aphids in those plots. The injury, however, was severe in all of the rows, and after the nfestation abated and the vines recovered, the plants in all of the plots were more or less alike in appearance.

As may be seen from the data in table 28, the average increase in yield of the nicotine plots over the checks was about four times its probable error, and this indicates superior insecticidal properties for the dusts containing nicotine.

TABLE 28. YIELD OF GREEN MOUNTAIN POTATOES DUSTED WITH NICOTINE DUSTS AND WITH A COPPER-LIME DUST CONTAINING NO NICOTINE, 1921

(Farms of C. E. Dimon, Southampton, New York, and H. S. Ludlow, Bridgehampton, New York)

Dust	Yield, in bushels per acre	
	Experiment 1	Experiment 2
Copper-lime	259.0	277.8
Copper-lime with nicotine	289.0	255.8
Contact Special	....	262.8
Copper-lime	295.0	252.0
Copper-lime with nicotine	302.0	253.2
Contact Special	....	242.7
Check (not dusted)	....	218.6
Copper-lime	270.0	255.8
Copper-lime with nicotine	265.5	230.4
Contact Special	....	240.5
Copper-lime	258.3	237.0
Copper-lime with nicotine	278.0	240.0
Contact Special	....	249.0

Average increase in yield of copper-lime dust with nicotine, over copper-lime dust:

Experiment 1 = 14.42 ± 3.54
Experiment 2 = 7.31 ± 5.33

Average increase in yield of Contact Special over copper-lime dust:

Experiment 2 = 0.15 ± 3.20

Experiment 2, 1921 (Farm of H. S. Ludlow, Bridgehampton, New York). — In the second experiment, both the copper-lime contact dust and the sulfur contact dust (Contact Special) were used with the copper-lime dust

without nicotine. The arrangement of the plots is indicated by their sequence in table 28. Each plot contained four rows and was 20 rods long. All of the rows of each plot were dug and weighed. Three applications of a copper-lime dust were made by the grower before the experiment was begun, and two were made after the infestation of aphids. Four applications of the Special Contact dust were made. One plot of four rows received no treatment of any kind during the time of the experiment.

Late-blight infection was light even in the check plot, and was more noticeable in the plots protected with the Contact Special than in those dusted with the copper dusts. Injury from flea beetles and from tipburn was about the same in the dusted plots but was more severe in the check. The plots dusted with the Contact Special showed fewer aphids and less injury than did the check plot or the plots dusted with the copper-lime dust. The degree of control was slightly in favor of the copper lime contact mixture, but was not so marked as that described for experiment 1. In referring to the data on yields, in table 28, it is seen that there were no significant differences in the yields of the differently treated plots. The slight degree of aphis control was not reflected in the yields.

Experiment 3, 1922 (Farm of H. T. Fahy, Bridgehampton, New York). —The third experiment was conducted to test further the effectiveness of the copper-lime contact dust. There were four plots dusted with this mixture, alternating with four plots dusted with a copper-lime dust containing no nicotine. The plots were four rows in width and 38 rods in length. Three applications were made in a field that had been sprayed by the grower before the infestation of aphids appeared. The infestation was heavy again that year, and by the time the second application was made the younger parts of the shoots were severely curled. Thorough examination of the plants in the experimental plots and of those in the sprayed rows on either side showed little difference in the number of lice present after the three applications. Examinations were made about one hour after, and again three days after, each application. There were no general differences in the degree of injury or in the appearance of the vines, in the differently treated plots. The experimental plots were not dug. The control of aphids with nicotine dust was not so marked in that season as in 1921.

INJURY TO POTATO PLANTS FROM FUNGICIDES CONTAINING COPPER

For the more recent investigations on the morphological and physiological effects of copper fungicides on potato plants, together with rather complete bibliographies and reviews of the earlier literature, the reader is referred to the works of Barker and Gimingham (1914), Lutman (1916), Duggar and Bonns (1918), Butler (1922), and Cook (1923).

Concerning the effects of the fungicides on plants in the foregoing experiments conducted on Long Island and in Washington County, there was no opportunity to ascertain any beneficial effect on the vines other than the protective action against fungous diseases, insects, and tipburn. In every experiment there was at least one or more of these sources of injury entering to influence the length of the growing period and the yield of the plants.

It is a well-known fact that vegetable and fruit growers, in prosecuting their plans for protection against diseases and insect pests, must take into consideration the liability of the plants to the so-called "bordeaux injury." The foliage of some plants is distinctly more susceptible than that of others to this type of injury. Practically all of the workers who have investigated the cause of the injury, attribute it to the absorption, in one way or another, of soluble copper. The symptoms seem to vary from local dead spots in the leaf, to partial or complete defoliation.

In the experiments extending over a period of three years in Suffolk County and one year in Washington County, there was no indication whatever of any local lesions on the stalks or the leaves, typical of the so-called "bordeaux injury," where copper sulfate and lime were employed in formulae varying from 4–4–50 to 7–7–50, or in corresponding formulae in which the ratio of hydrated lime was reduced to one-half. The same results were obtained in the greenhouse during the winter and spring months. Although the tipburn was believed to be the cause of the excessive foliage injury observed on foliage sprayed with sal-soda-bordeaux as compared with the amount of that type of injury in the plots sprayed with lime-bordeaux or dusted with copper-lime dusts, yet it appeared that in some cases the coating of the sal-soda-bordeaux was too heavy to afford so little protection against tipburn. Consequently it would not be surprising if a part of that type of injury was caused by substances in the preparation itself. Bedford and Pickering (1910), Butler and Smith (1919), and others have shown that if sal soda and copper sulfate are not mixed in the proper proportions, there may exist an excess of copper sulfate or sodium bicarbonate in solution, either of which may prove injurious to potato foliage.

Regarding foliage burn produced by the copper-lime dusts, no signs of such injury were noticed in 1920 with the use of the commercially mixed Sanders' dust containing 6 per cent of copper, or in 1921 with the same preparation used in Washington County. Furthermore, in the experiments in Suffolk County in 1921, when farm-mixed copper-lime dusts containing respectively 6, 8, and 10 per cent of metallic copper were applied to damp foliage, no injury from the materials was observed.

In the summer of 1922 an experiment was conducted for the purpose of determining the relation between the ratio of monohydrated copper sulfate, containing about 33 per cent of copper, to hydrated lime, and the degree of copper injury to potato foliage. The size and the arrangement of the plots, together with the composition of the dust mixtures, are given in table 29. Eleven applications were made with a hand duster at intervals of about seven days. With the exception of one application, all were made in the morning when there was little wind and when the foliage was wet. Rather heavy and very thorough applications were made by dusting each row from both sides, to give a two-nozzle-to-the-row effect. An attempt was made throughout to apply equivalent amounts of copper per acre in all of the plots. Observations were made frequently between applications, in order to ascertain the relative degrees of burning.

It will be recalled that in the experiments of 1922 on the control of diseases and insects, it was found that the dust mixture containing 10 per cent of copper produced a slight amount of burning, and was for that

TABLE 29. RESULTS OF A FIELD EXPERIMENT SHOWING THE RELATION BETWEEN THE RATIO OF MONOHYDRATED COPPER SULFATE TO HYDRATED LIME IN COPPER-LIME DUSTS, AND THE DEGREE OF BURNING ON THE FOLIAGE OF GREEN MOUNTAIN POTATOES, 1922

Length of plot (yards)	Number of rows in plot	Dust	Per cent of copper	Ratio of monohydrated copper sulfate to hydrated lime	Degree of copper injury or burning on the foliage
8.....	4	Copper-lime.....	20.0	1:0.5	Very severe
12.....	4	Copper-lime.....	17.1	1:0.75	Severe
21.....	2	Copper-lime.....	15.0	1:1	Considerable
27.....	2	Copper-lime.....	12.0	1:1.5	Slight
33.....	1	Check.....	....	.....	.....
36.....	2	Copper-lime with Kayso..	10.0	1:2	Very slight
44.....	2	Copper-lime.....	10.0	1:2	Very slight
50.....	2	Copper-lime.....	7.5	1:3	None
58.....	2	Copper-carb with lime...	10.0	.....	None
68.....	2	Copper-lime with gypsum.	10.0	1:1	Considerable

reason replaced until later in the season by a dust with 8.5 per cent of copper. The 8.5-per-cent dust produced no apparent injury, nor did the 10-per-cent dust later on when the vines were older. In the experiment outlined in the preceding paragraph, when the freshly mixed dusts were applied to wet foliage, copper burning was evident wherever dusts containing 10 per cent or more of copper were applied (table 29); and the higher the ratio of copper sulfate to hydrated lime, the greater was the injury. No injury was observed on the foliage dusted with the 7.5-per-cent copper dust, and only a slight amount in the first half of the season with the 10-per-cent mixture. The Copper-carb dust produced no burning whatever. The copper-lime dust in which gypsum, hydrated lime, and monohydrated copper sulfate were used in equivalent amounts, produced the same degree of burning as did the copper-lime dust with the same ratio of copper sulfate and lime but no gypsum.

The type of burning resulting from the use of dusts containing 12 and 15 per cent of copper was distinguished by the presence of numerous minute "burned" spots scattered over the leaves (figure 7). When examined closely, each spot appeared as a colorless, circular ring with a brownish, dead center. Such was the appearance from one to three or four days after each application. Later, the center of the lesion might fall away, leaving a perforation similar to those resulting from the feeding of flea beetles. Injury from the dusts higher in percentage of copper included, in addition to the small burned areas, larger patches of reddish brown, dead tissue which became dry and brittle (figure 8). The entire leaflet, expecially if a young one, might become rigid, curled upward at the margins, and retarded greatly in growth.

Experiments conducted in the greenhouse during the winter and spring, where diseases and insects were not present, gave results corresponding closely with those obtained in the field. The degree of burning, however,

FIGURE 6. LEAVES FROM CONTROL PLANT, SHOWING NO COPPER INJURY

FIGURE 7. LEAVES DUSTED WITH A COPPER-LIME DUST CONTAINING 15 PER CENT OF COPPER, SHOWING A LIGHT DEGREE OF INJURY

FIGURE 8. LEAVES DUSTED WITH A COPPER-LIME DUST CONTAINING 20 PER CENT OF COPPER, SHOWING SEVERE INJURY

was slightly greater in the case of each dust, than was observed under field conditions. Bliss Triumph plants appeared to be more susceptible to this type of injury than did Irish Cobbler or Green Mountain plants. Furthermore, in view of the fact that in well-controlled greenhouse experiments it was found that the nature of the burning resulting from the copper-lime dusts was practically identical with that produced by applying varying amounts of monohydrated copper sulfate itself to wet foliage, or aqueous solutions of blue vitriol of varying concentrations, the cause of the burning was attributed to the entrance of soluble copper salts into the leaf. Also, when dehydrated copper sulfate or dusts high in percentage of copper were applied heavily to wet foliage, and the foliage was washed thoroughly immediately afterward to remove practically all of the coating, the amount of burning was very slight, indicating a probability that the injury was not due to the slight amount of heat evolved during the hydration of the dehydrated copper sulfate. When copper-lime dusts high in copper content, or dehydrated copper sulfate, were dusted on dry foliage, no burning resulted until the plants were moistened.

Regarding the stunting effect on plants receiving a relatively heavy coating of bordeaux mixture or copper-lime dust (pages 44 and 49), the same condition was observed in the hand-dusted experiment conducted to determine the amount of copper injury due to copper-lime dust. The heavier the coating of dust on the foliage, the more noticeable was the stunting effect on the plant as a whole, even in the plots that showed no

copper burning whatever. Furthermore, judging from the yields in the experiment of 1922, in which there was a comparison of the dusting of dry plants with the dusting of wet vines, it appears that this dwarfing might be accompanied by a reduction in yield (table 24, page 48). At any rate, the plants which were dusted when dry, and which for that reason possessed a very light coating of dust, produced a significantly higher yield than did those which were dusted when wet and therefore possessed a heavier coating of the fungicides. This difference of nearly ten bushels in yield was obtained in spite of the fact that the plants with the heavier coating of dust sustained less injury from fungous diseases and insects than did the other plants.

CHANGE IN SOIL REACTION RESULTING FROM APPLICATION OF FUNGICIDES

A few potato growers who had experienced difficulty with potato scab, questioned the advisability of using the copper-lime dust because of the probability of increasing the alkalinity of their soils through the application of so much lime. In order to determine whether or not any of the fungicides brought about a change in the reaction of the soil, a number of soil samples were taken in 1922 from plots that were treated with copper-lime dusts varying in percentage of lime, and from plots that were treated with bordeaux mixture. The samples were taken after digging. In determining the hydrogen-ion concentration of the soils the colorimetric method was used, employing Clark and Lubs' (Clark, 1920) color chart and standard buffers.

The results of the tests are given in table 30 and represent the averages of seven separate determinations. There appears to be an indication, in the Bridgehampton experiment, that the dusted plots showed a slight increase in alkalinity over the checks. In the duplicate experiments at

TABLE 30. RESULTS OF HYDROGEN-ION DETERMINATIONS OF SOIL SAMPLES TAKEN FROM DUSTED AND FROM SPRAYED POTATO PLOTS, 1922

Fungicide applied to plots from which tests were made	Number of applications of fungicide	Hydrogen-ion concentration, in terms of pH	
		Experiment at Southampton	Experiment at Bridgehampton
Copper-lime dust, 10 per cent of copper	13	4.86	4.88
Bordeaux mixture varying from 4–4–50 to 7–7–50	13	4.76	4.75
Checks*	..	4.84	4.71
Copper-lime dust, 7.5 per cent of copper	11	4.83	....
Copper-lime dust, 17.1 per cent of copper	11	4.70	....
Copper-lime dust, 10 per cent of copper, applied to dry foliage	13	4.83	....
Copper-lime dust, 10 per cent of copper, applied to wet foliage	13	4.88	....

* Two applications of a lime-calcium-arsenate mixture were made at the beginning of the spraying season.

Southampton, however, such a difference is not evident. Furthermore, at Southampton, where all of the plots were located in the same small field, which was level and appeared to be comparatively uniform throughout in the nature of the soil, there were no appreciable differences in the results of the copper tests, unless the value of pH 4.70 be considered significantly less than pH 4.83 and pH 4.88. Since the results in the duplicate dusting and spraying experiments were not consistent, and since there is no great difference between any two values in the table, it is doubtful whether the differences obtained are indicative of any appreciable changes in the hydrogen-ion concentration of the soil as brought about by the application of the fungicides.

RELATIVE COSTS OF DUSTING AND SPRAYING

In comparing the costs of dusting and spraying, the estimates were based on prices for 1922. Not all of the minor items of cost that might enter into the situation were considered. The principal items concerned are as follows: (1) the price of ingredients; (2) the time required to protect a given number of acres, together with the value of the time of men and teams; (3) the cost of mixing in the case of dusting, and of pumping or drawing water, making stock solutions, and so forth, in the case of spraying. It was assumed that the price of dusting and spraying machinery is about the same. There are other items that might be included, expecially if one wished to compare accurately the cost of dusting with home-mixed dusts and with commercially mixed dusts, because the latter involve such minor items in their preparation.

The estimates given in table 31 are based on the cost of protecting 25 acres, which is the average of about one day's dusting. The duster in use

TABLE 31. COST OF DUSTING AND SPRAYING IN 1922, APPLYING 3 POUNDS OF COPPER PER ACRE

(1) Cost of dusting with home-mixed copper-lime dust containing 10 per cent of copper and no arsenates:	
Price of monohydrated copper sulfate	$ 0.14
Price of hydrated lime	0.0125
Cost of mixing 750 pounds (for 25 acres)	0.75
Total cost of 750 pounds of dust	41.75
Cost of man and team for 9 hours, at 90 cents an hour	8.10
Total cost of dusting 25 acres	49.85
(2) Cost of spraying with bordeaux mixture 6–6–50, applying 100 gallons per acre:	
Price of 12 pounds of blue vitriol	$ 0.85
Price of 12 pounds of hydrated lime	0.15
Cost of materials for one tank	1.00
Cost of materials for 25 acres	25.00
Cost of preparing the spray mixture	1.00
Cost of man and team for 14 hours, at 90 cents an hour	12.60
Total cost of spraying 25 acres	38.60
(3) Cost of dusting 25 acres with commercially mixed copper-lime dusts containing no arsenates:	
(a) Containing 6 per cent of copper and purchased at 7 cents a pound	$95.60
(b) Containing 7 per cent of copper and purchased at 8 cents a pound	$93.70
(c) Containing 8 per cent of copper and purchased at 10 cents a pound	$101.85

was an engine-power, four-row machine, and the sprayer was a traction-power, six-row machine with two nozzles to a row. Both fungicides were applied at the rate of 3 pounds of copper per acre. It is seen that when home-mixed dust was used, although 25 acres were protected in two-thirds of the time in which they could have been sprayed, the cost of dusting was about 29 per cent higher. Furthermore, dusting with the purchased mixtures was considerably more than twice as expensive as spraying. It should be remembered, also, that with the type of duster in use in 1922, there was considerably less copper retained by the foliage for each pound of copper applied per acre, than in the spray, and that the loss from the leaves was greater. There are certain conveniences connected with dusting, however, which overcome some of the objectionable features of spraying, and these should receive their share of consideration in comparing total costs.

SUMMARY

The membranes formed when copper-lime dust is wetted are similar to those in bordeaux mixtures rich in lime, but they remain entire, not broken and scattered as in the spray.

When light applications were made of copper-lime dust and of dilute bordeaux mixture to give the same amount of copper per unit of area, a larger percentage of this area was covered by the spray membranes, due to their greater number and greater surface area, than by the dust membranes.

Under field conditions, about 44 per cent more copper for each unit amount applied per acre was retained by the foliage sprayed with bordeaux mixture than by the dusted foliage; and although a greater quantity of the copper was lost from the sprayed plants between applications, the percentage loss was less than that from the dusted plants. In greenhouse experiments on both glass plates and potato leaves, the spray coating proved more resistant to washings than did the copper-lime dust coverings.

Under both greenhouse and field conditions, only about half as much dust was retained by dry potato foliage as by thoroughly moistened leaves, and under field conditions the rate of loss from the dry-dusted foliage was higher.

The two bordeaux powders tested, copper-carbonate dust and Sanders' green copper-arsenic dust, did not exhibit as great a degree of adhesiveness to potato foliage in the greenhouse as did the copper-lime dust, due presumably to the fact that when the bordeaux powders are wetted no colloidal membranes are present. The rate of washing of the Copper-carb from the foliage was more than twice as high as that for the copper-lime dust.

The casein spreader, Kayso, produced no effect on the adhesiveness of either the copper-lime dust or the bordeaux mixture, but it increased, to a marked extent, the spreading qualities of the spray.

The amount of copper in rather high dilutions of bordeaux mixture necessary to inhibit germination of zoospores of *Phytophthora infestans* on glass slides, was found to be about 0.311 milligram per square meter. About twice this amount was required to prevent infection of plants in the greenhouse. In either case, the necessary amount of copper in the sprays was slightly less than that in the copper-lime dust, due no doubt to the greater covering power of the spray precipitate in mixtures of low concentration.

When equal amounts of copper were applied to damp foliage, in the copper-lime dust with a good hand machine or the best of the power dusters, and in the bordeaux mixture with exceptionally good sprayers, the control of early and late blight and of aphids appeared to be about equal in the two methods. The spray coating seemed to be superior in the control of flea beetles, leaf hoppers, and tipburn. Both of these fungicides were more effective against insects and tipburn than were sal-soda-bordeaux or the two proprietary bordeaux dusts, bordeaux-lead and Copper-carb.

The copper-lime dust when applied to dry foliage was less effective in controlling diseases and insect pests than when applied at the same rate to damp foliage, due to the greater amount that was retained by the moist leaves.

The various dusting machines used in the different experiments varied greatly in efficiency. Good hand dusters gave better results than did the power dusters used, due principally to a better distribution of the dust. To obtain an even distribution of dust on all parts of the plants, it seems to be essential that: (1) the nozzle should be so constructed that it will spread the dust into a wide stream so that the plants will be evenly enveloped; (2) there should be two nozzles to a row, so placed and directed as to produce a complete covering of the width of the row; (3) a blast of air should be created, sufficient to blow the dust out forcibly; and (4) the machine should feed evenly through the different nozzles.

There were strong indications, though no direct experiments to determine this question were made, that driving through the plots with sprayers or dusters produced injury to the vines, thus causing lower yields.

The results of the three years of experimentation in the comparison of copper-lime dust with bordeaux mixture, show that the sprayed plots produced an average gain in yield over the dusted plots of 7.2 bushels per acre. In all probability this increase is indicative, under the existing conditions, of the difference between the effectiveness of the two methods of protection.

Where copper-lime dusts containing respectively 6, 8, and 10 per cent of copper were used at rates so that equal amounts of copper were applied per acre, they showed no appreciable differences in the degree of protection against late blight and flea beetles, or in yields.

Sulfur, used either alone or mixed with hydrated lime, exhibited only slight protective properties against late blight, flea beetles, and tipburn. No injury to the foliage nor stunting of plants was observed.

In one experiment out of three, a copper-lime dust containing nicotine, when applied to damp foliage, proved superior to the same dust without nicotine in controlling aphids. A dust mixture known as "Contact Special," in which sulfur is the carrier, was not so satisfactory nor so effective for aphid control as was the copper-lime contact dust.

When freshly mixed copper-lime dusts containing from 10 to 20 per cent of copper were applied to wet foliage, there resulted a very slight burning of the leaves from the 10-per-cent dust and a severe injury from the 20-per-cent mixture, with a uniform gradation of burning between those limits. Dusts that contained less than 10 per cent of metallic copper produced no injury. The type of injury corresponded to that resulting when dehydrated copper sulfate is dusted on wet foliage, or when

a solution of blue vitriol is sprayed on dry foliage, and was attributed to the absorption of soluble copper salts.

There was strong indication, throughout the series of experiments, that heavy coatings of either dust or spray produced a dwarfing or a stunting effect on the plants. This effect was entirely independent of the occurrence of copper injury on the leaflets. There was repeated evidence also of plant injury, accompanied by reduction in yield, due to the passing of horses and machines through the plots.

The results of hydrogen-ion determinations made on samples of soils taken from plots that had received from eleven to fourteen applications of bordeaux mixture and copper-lime dusts, showed no significant difference in reaction from that in the check plots.

Based on the price of dusting and spraying materials in 1922, when 3 pounds of copper was applied per acre in each application, it cost about $2 to dust an acre once with home-mixed copper-lime dusts, $1.50 to spray an acre once, and from $3.75 to $4 to treat an acre once with commercial brands of dust.

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